SUMMARY OF CONTENTS OF

BULLETIN OERLIKON

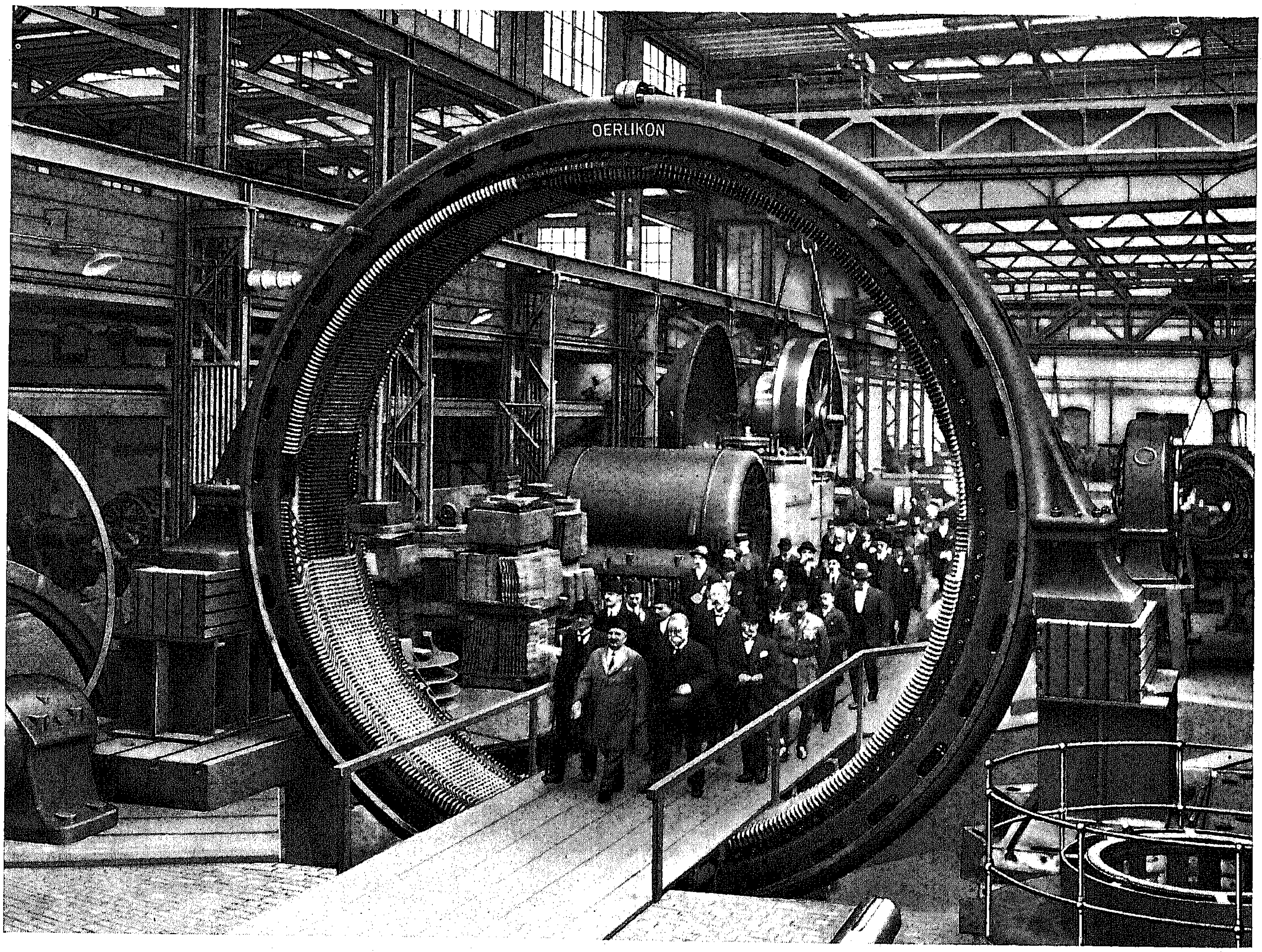
1930

ATELIERS DE CONSTRUCTION OERLIKON, OERLIKON

BULLETIN OERLIKON

No. 103 — January 1930

Contents:

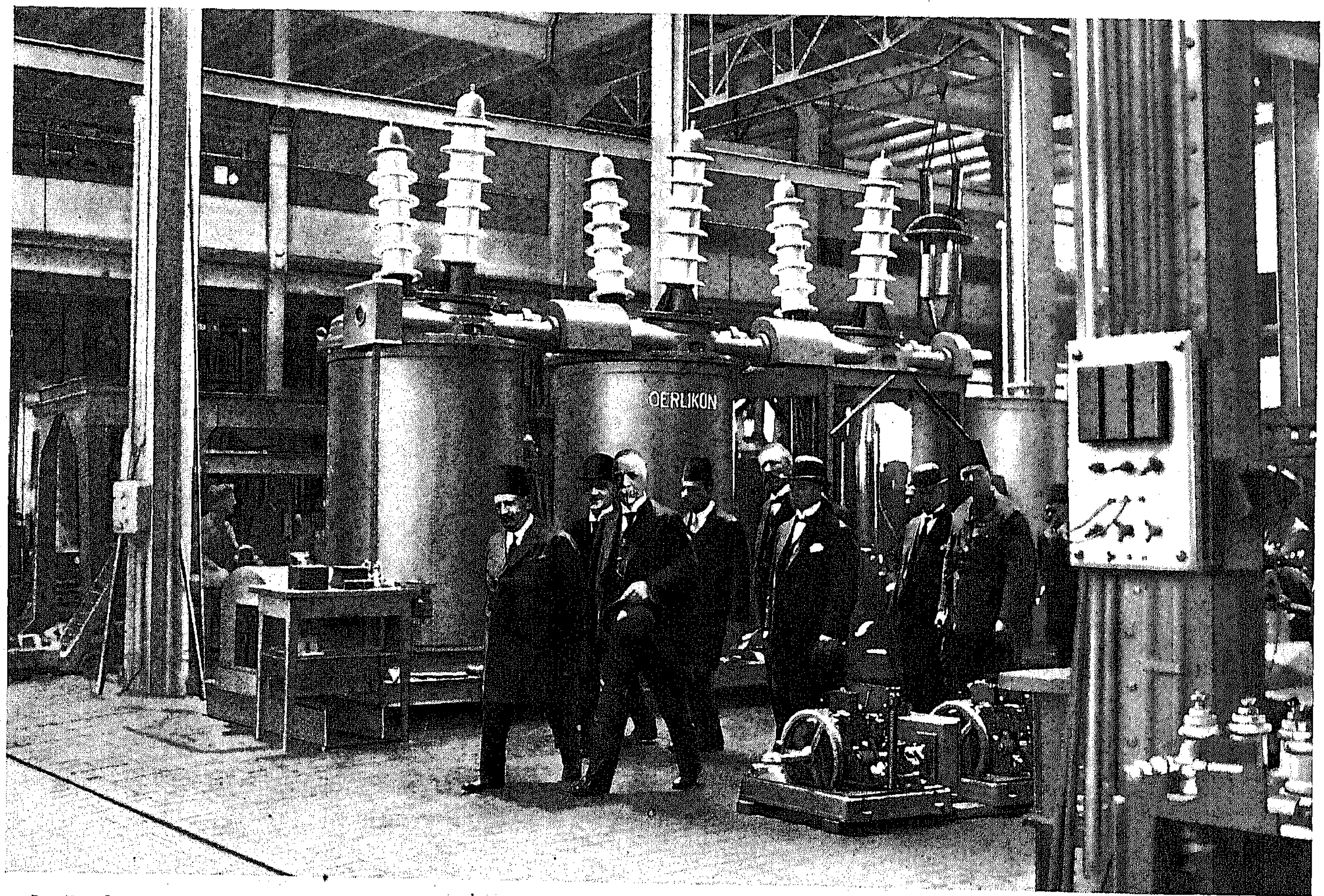


VISIT OF KING FUAD I TO THE OERLIKON WORKS.

In the centre: Stator of a three-phase generator for the Laufenburg Power Station.
13,000 KVA — 6400 Volts — 50 cycles — 125 rpm.
Diameter of bore 19′ 8″ — Weight of stator 47 tons — Weight of rotor 80 tons.

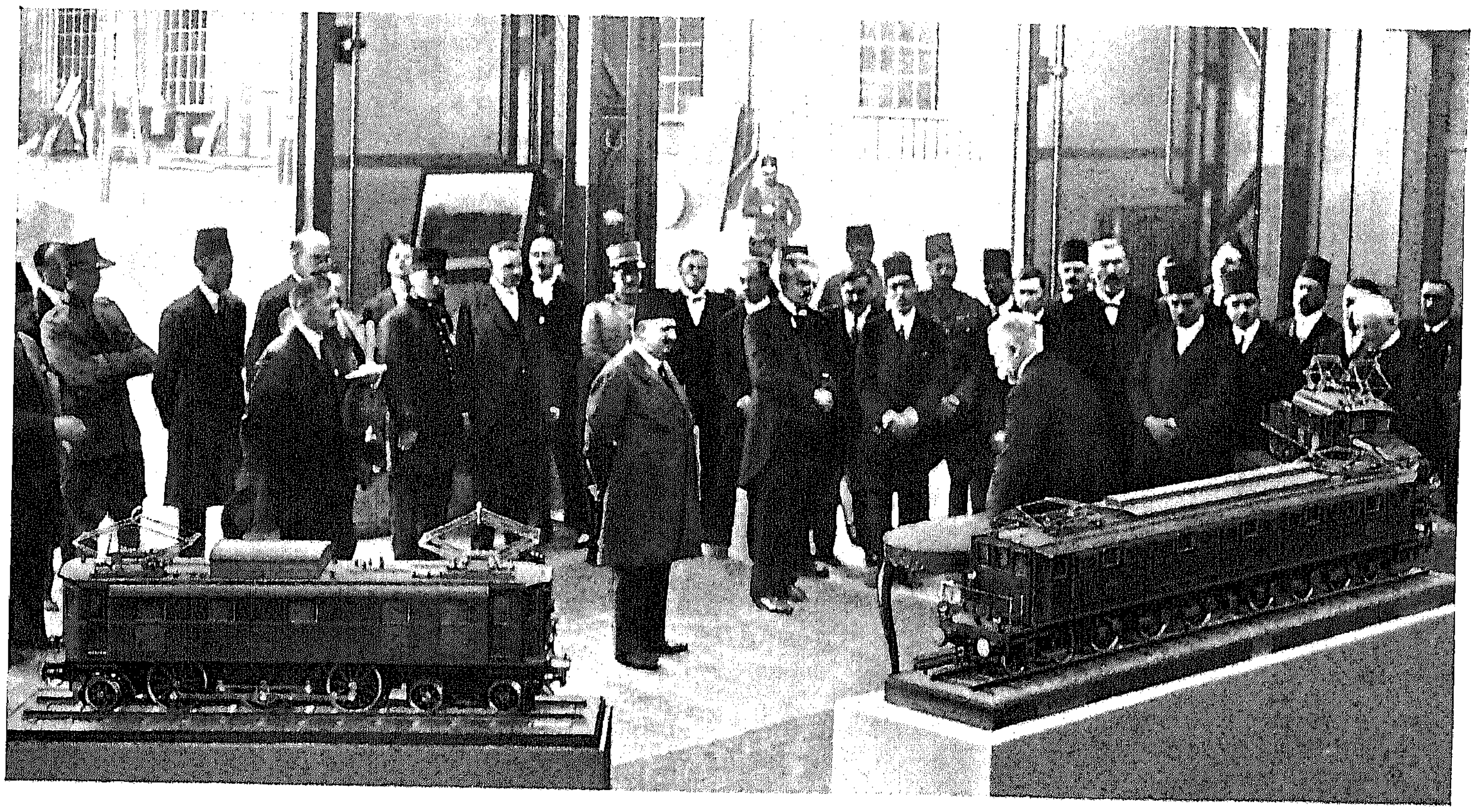
VIEWING THE WORKSHOPS FOR SMALL MACHINES, THE TEST ROOM FOR THE TESTING OF MATERIALS AND THE SWITCHGEAR SHOPS.





In the background: Triple-pole outdoor type oil circuit breaker for 112,500 Volts. Rupturing capacity 700,000 KVA. Weight per circuit breaker, including oil, 16 tons.
12 Equipments supplied to the Burguillo and Puente Nuevo power stations of the Saltos del Alberche Company, Madrid.

ATELIERS DE CONSTRUCTION OERLIKON, OERLIKON



In the locomotive shops.

Visit of King Fuad I to the Oerlikon Works

on the 4th July 1929.

King Fuad I of Egypt, accompanied by the President of the Swiss Confederation, Dr. R. Haab, and two Members of the Federal Council, Messrs. Motta and Pilet-Golaz, as well as by a number of other gentlemen, visited the Oerlikon Works on the morning of the 4th July.

King Fuad I arrived at Oerlikon from Winterthur shortly before 12 o'clock, where he was received by the Chairman of the Board of Directors, Col. Schindler, and by the Management; he then made a half-an-hour's tour of inspection of the Works and was shown in succession the shops for small machines, the test room for the testing of materials, where he witnessed a flash-over with half-a-million volts, the shop for heavy machines, the large erection shop, where the stator of a generator for the Laufenburg power station was the object of special interest, the switchgear shops and the locomotive shops, where the most important types of new locomotives for the Swiss Federal Railways were being erected. The workmen's mid-day interval was altered on that day to before the time of the visit, and the workmen were given a lunch by the Works.

In the locomotive shops, the Chairman of the Board of Directors, Col. Schindler, presented King Fuad I and the President of the Swiss Confederation with the Works Gold Medal of the Oerlikon Company, and made the following address:—

Sire, Monsieur le Président de la Confédération Suisse,

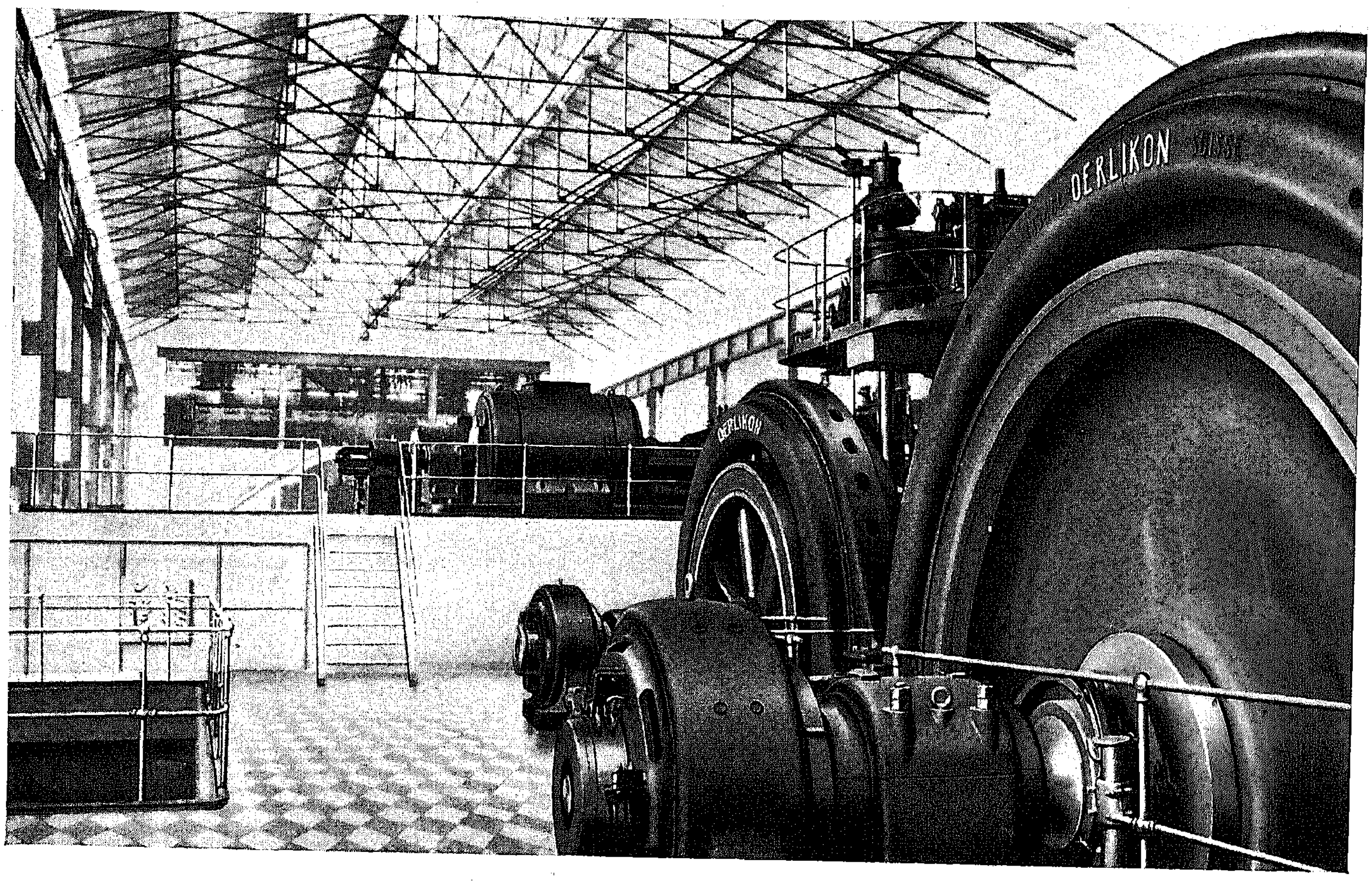
Le Conseil d'Administration des Ateliers de Construction Oerlikon demande à Votre Majesté et à Monsieur le Président de la Confédération Suisse, de lui faire l'honneur d'accepter la médaille du Travail Oerlikon. Cette médaille a été créée en vue de récompenser la longue durée du travail de nos collaborateurs, ainsi que les éminents services rendus à notre Société ou à l'Industrie en général. Les deux premiers exemplaires de la médaille d'or ont été frappés pour ce jour mémorable.

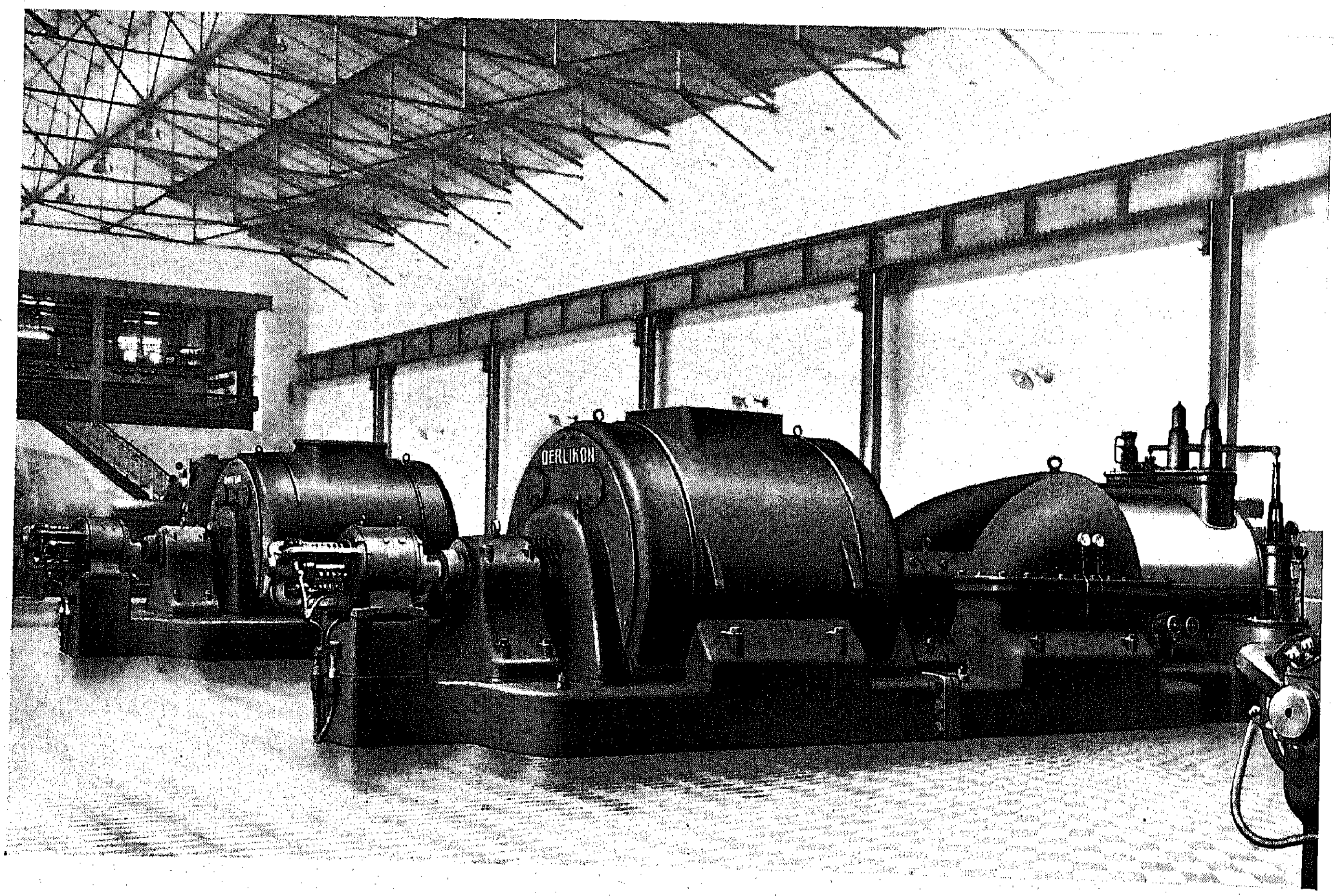
En témoignage de notre admiration pour les œuvres immortelles de l'antique civilisation égyptienne, œuvres qui ont constitué les bases de nos travaux modernes, daigne Votre Majesté accepter la médaille d'or du Travail Oerlikon.

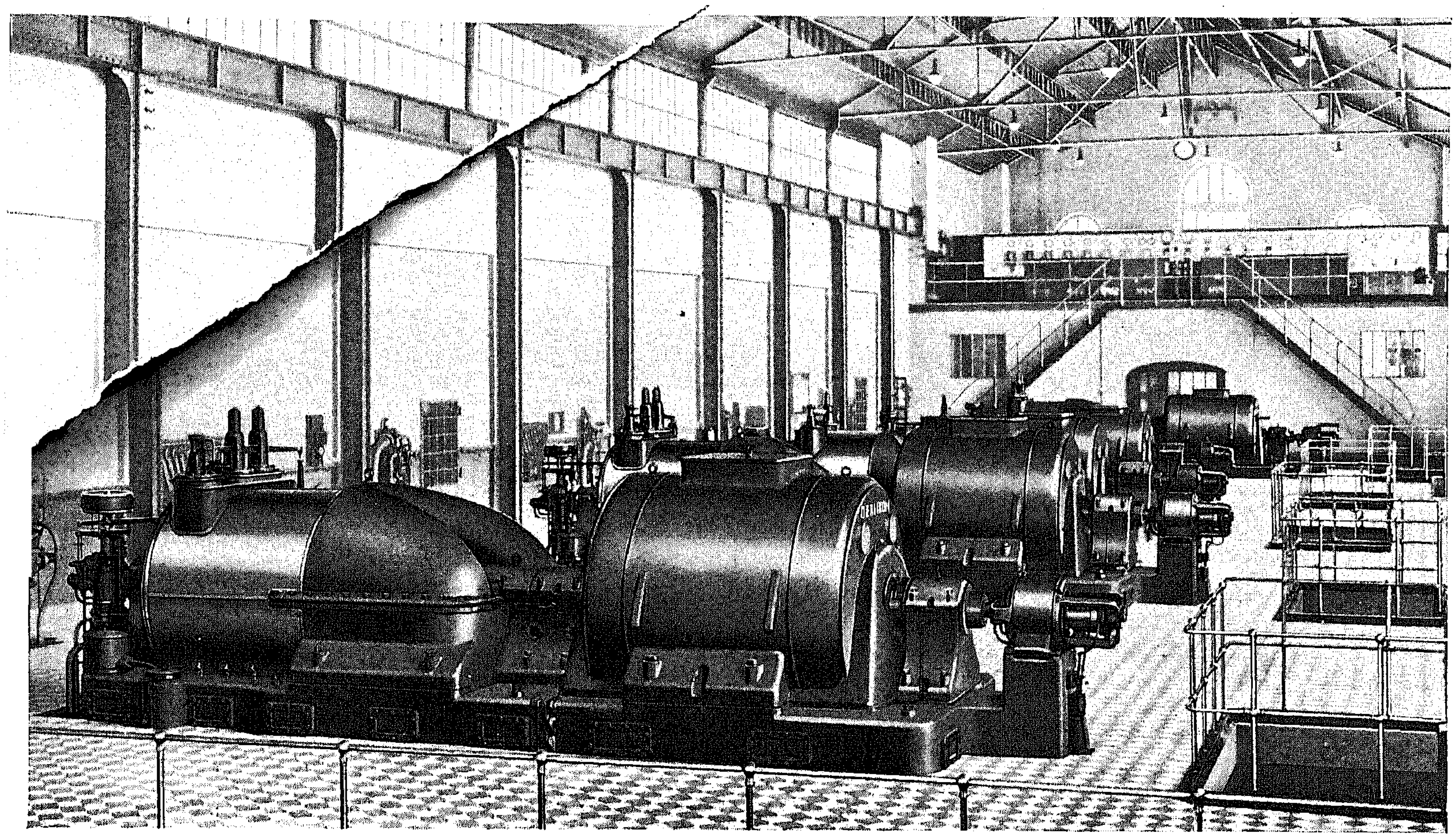
Le Conseil d'Administration d'Oerlikon prie aussi le Président de la Confédération Suisse de vouloir bien accepter la médaille, en reconnaissance des grands services que la Confédération et Monsieur le Docteur Haab en sa qualité de Chef du Departement des Chemins de fer ont rendu à l'industrie suisse, en particulier à un moment où le chômage menaçait de porter un dommage considérable au peuple et à l'industrie suisse. Par l'entreprise grandiose de l'Electrification des chemins de fer le danger fut écarté et l'industrie maintenue en activité.

Que Votre Majesté me permette de lui remettre aussi le Mémorial des Ateliers de Construction Oerlikon, récemment rédigé à l'occasion du cinquantième anniversaire de la fondation de nos usines. Votre Majesté y trouvera une histoire de notre établissement et de son développement jusqu'à ce jour, sauf notre dernière création, la plus grande locomotive de l'Europe que nous avons récemment fournie au Chemin de fer de Paris à Lyon et à la Méditerranée.

CAIRO ELECTRICITY WORKS.
5 OERLIKON turbo-generator sets and 2 OERLIKON Diesel-generator sets.







ALEXANDRIA ELECTRICITY WORKS. 5 OERLIKON turbo-generator sets.

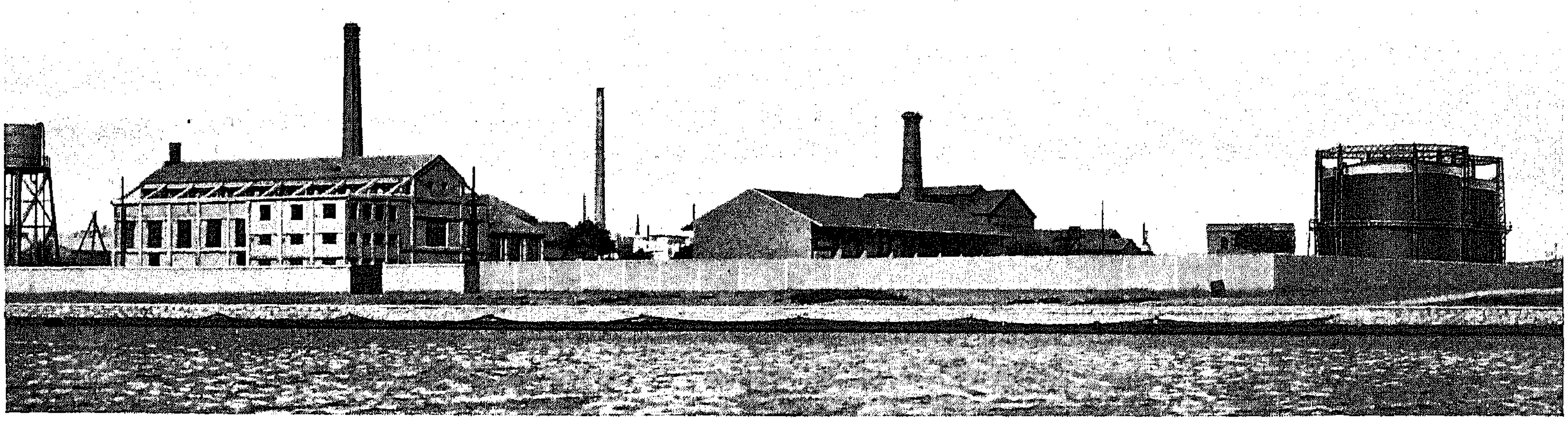
OERLIKON Plant in Egypt.

The large towns of Egypt, and more especially those situated in the rich districts of the Delta of the Nile, went through a period of rapid expansion at the end of last century, like many of our great European cities.

Cairo, Alexandria, Port Said, amongst others, increased their commercial activities, carried out important public works, modernised or developed their plant and improved their housing as well as the comfort of the hotels frequented by rich patrons and tourists come from afar to visit the ancient remains of a past civilisation.

Town lighting was applied more and more extensively and as far back as 1865, that is to say, soon after the introduction of gas lighting in Paris, by the Philippe Lebon process, European engineers were invited to come and give Egypt, too, the benefit of this useful discovery.

Works were erected at Alexandria and Cairo, and subsequently at Port Said, and these first developments were heartily welcomed on all sides. Gas lighting was, as in Europe, soon supplemented by electric lighting, and since then gas and electricity have jointly supplied the needs of the population, the former being mainly used for domestic purposes and heating, and the latter for lighting and power.



PORT SAID ELECTRICITY WORKS.

ATELIERS DE CONSTRUCTION OERLIKON, OERLIKON

It was in 1893 that the first electric power stations were erected in Egypt. At the outset, however, the demand for electric power only increased very slowly, but, after 1901, the power consumption curve rose very rapidly and it became necessary to build more and more important power stations. On the other hand, the Suez Canal which had been opened in 1869 and linked up Port Said on the Mediterranean and Port Thewfik on the Red Sea had created new demands increasing from year to year with the traffic handled.

Owing to the growing importance of Port Said, it was soon necessary to provide, there, an adequate power supply to meet the needs of the yards and workshops connected with the port and the Canal, as well as for town lighting.

At the same time, the Suez Canal Company had to erect very important new workshops and stores, and ordered from the Oerlikon Company the 12 electric travelling cranes for 2, 5, 15 and 45 tons required. A special feature of the hoisting gear of the three 45-ton travelling cranes is the pole-changing switch controlled from the driver's cab, by means of which two speeds of motor can be obtained — a slow speed for the heavy loads and a high speed for the light loads.

The fresh water supply for the Canal district is ensured by a canal bringing the water of the Nile from near Cairo to Suez, while a branch canal runs from Ismailia to Port Said. A pumping station was erected, in this connection, at Port Said; it comprises 3 electric pump sets which serve to raise the water to filtering tanks, and 6 further electric pump sets for dealing with the filtered water. Four of the latter work against a head of 115 feet and deliver 1650 galls/min. The motors and transformers of this pump station have been supplied by the Oerlikon Company.

Messrs. Lebon & Co. built the first electric power stations in Alexandria and Cairo, and a little later provided the town of Port Said, too, with a modern installation. The electric power demand increased as these towns expanded, and, at the present time, the power stations supplying their requirements are equipped with machines of the very latest design. The boiler plant comprises more than 30 boilers, each producing 11000 to 16500 lbs/hour of steam; they are designed for firing with pulverised coal or crude oil, a method as yet little used in Europe. These installations are, however, the first and still the only ones worked on this system in Egypt.

The Oerlikon Company has had a large share in equipping these power stations and has supplied turbo-generators, transformers, switchboards and control gear for the purpose.

At the Alexandria power station, for instance, the plant comprises a turbo-generator set for 1600 KW, one for 2250 KW, two for 4100 KW and one for 4700 KW, as well as a phase advancer equipment for 600 KW.

All these turbo-sets generate three-phase current at 2000 volts, 40 cycles, and feed, through the intermediary of 2000 volt busbars, three-phase and single-phase circuits; all the latter are provided with induction regulators serving to maintain the pressure of 2000 volts constant in the feeders. Furthermore, additional single-phase circuits at 5000 volts [illegible] are fed by transformers with a total capacity of 1500 KV[illegible] A step-down transformer is provided in the case of eac[illegible] [illegible] for supplying the power required for driving th[illegible] [illegible] sets of the condenser of the turbine. Thes[illegible] transformers [illegible] also all be used to supply current to th[illegible] auxiliary busbars [illegible] 173/100 volts, to which various statio[illegible] transformers with a total capacity of 780 KVA are connecte[illegible] This low tension system feeds also a motor generator set f[illegible] the charging of the three batteries of accumulators supplyin[illegible] the direct current for the requirements of the switchboar[illegible]

In the case of the Cairo power station, the equipmen[illegible] is more varied; it comprises Diesel engine sets for 800 an[illegible] 1500 HP, running at low speed, also a turbo-generator se[illegible] for 800 KW, two for 4100 KW and two for 475[illegible] KW. Th[illegible] small sets generate three-phase current at 3500 volts, 4[illegible] cycles, the neutral point of generators being brought ou[illegible] so that a pressure of 2000 volts is also available, between phase and neutral point. The 4 large sets for more than 4000 KW have, however, been designed by the Oerlikon Company to give directly, at the terminals, a pressure of 10000 volts. The power is distributed at different pressures. There are single-phase and three-phase circuits at 10000 volts, several of these with induction regulators, also single-phase circuits at 2000 volts, and three-phase circuits at 3500 volts, with induction regulators too. A three-phase transformer for 1500 KVA, with pressure regulator, has been provided between the 3500 / 2000 volt and 10000 volt busbar systems. This transformer permits of numerous combinations during service, with a view to ensuring a supply at all the different pressures, even when the number of sets in service is very much reduced and does not include units of the different sizes.

As in the case of the Alexandria power station, step-down transformers supply the power required for the auxiliary plant and can be used to feed the auxiliary busbars at 173/100 volts. This low tension system serves, here too, as supply for the motor generator set for the charging of the batteries of accumulators and for the requirement of the switchboard.

The Oerlikon Company has supplied for each power station a main switchboard equipped with the master switches and supervisory gear of the generators and the outgoing circuits, which permits of the control of the whole power station from the control room.

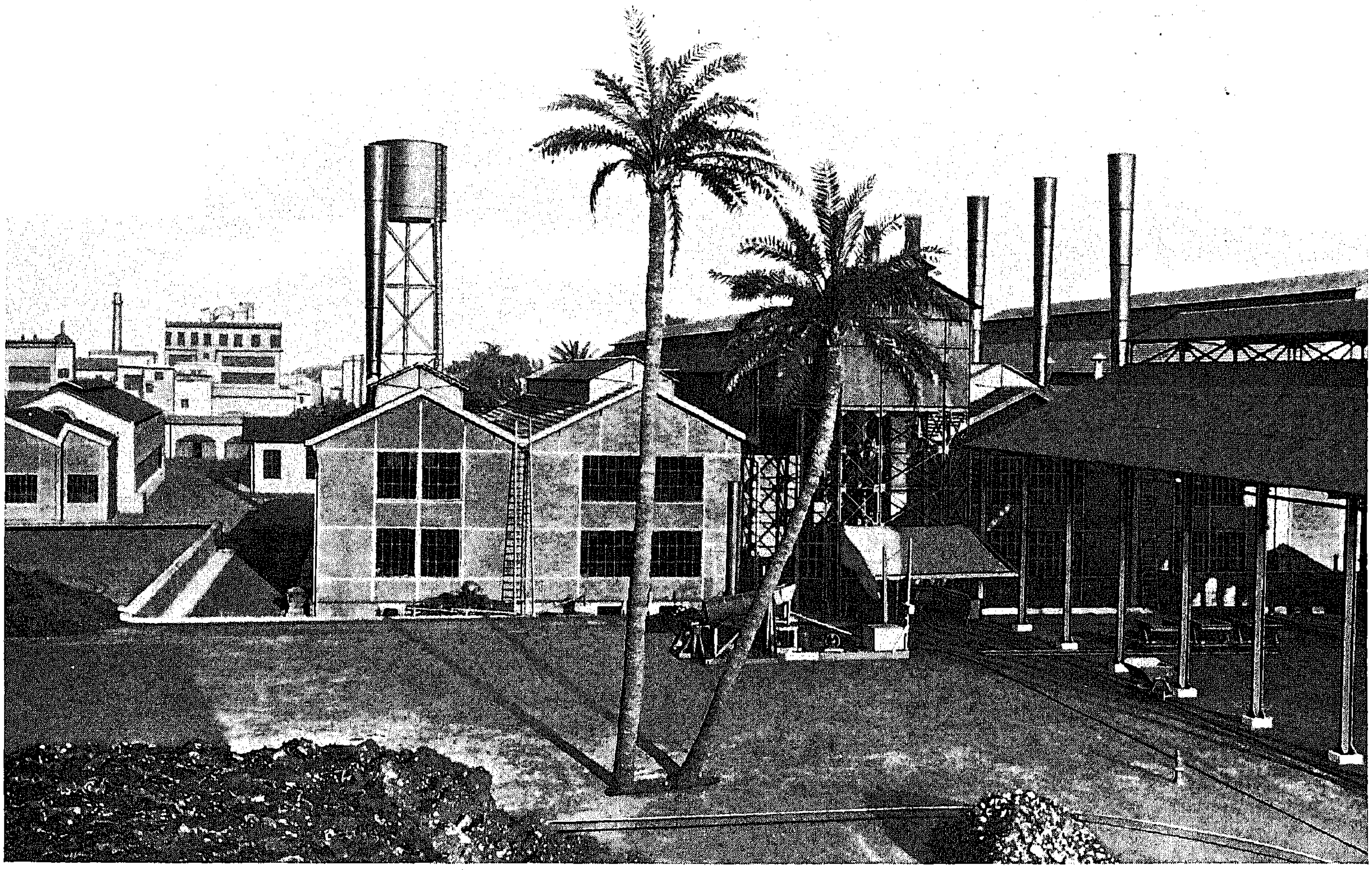
The Port Said power station is equipped with generators coupled to Diesel engines; the plant comprises four units for 5000 HP, one for 800 HP and one for 300 HP. All these sets generate three-phase current at 3000 volts, 40 cycles.

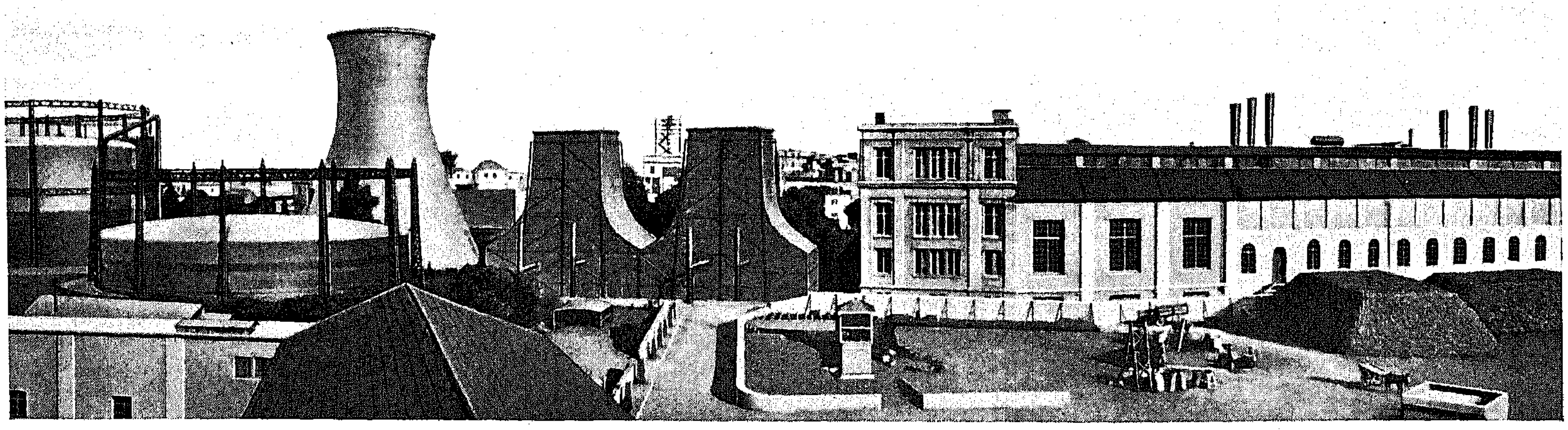
The Oerlikon Company has also supplied an 800 KW turbo-generator set for the Tantah power station of the Electric Power Supply Company of Lower Egypt.

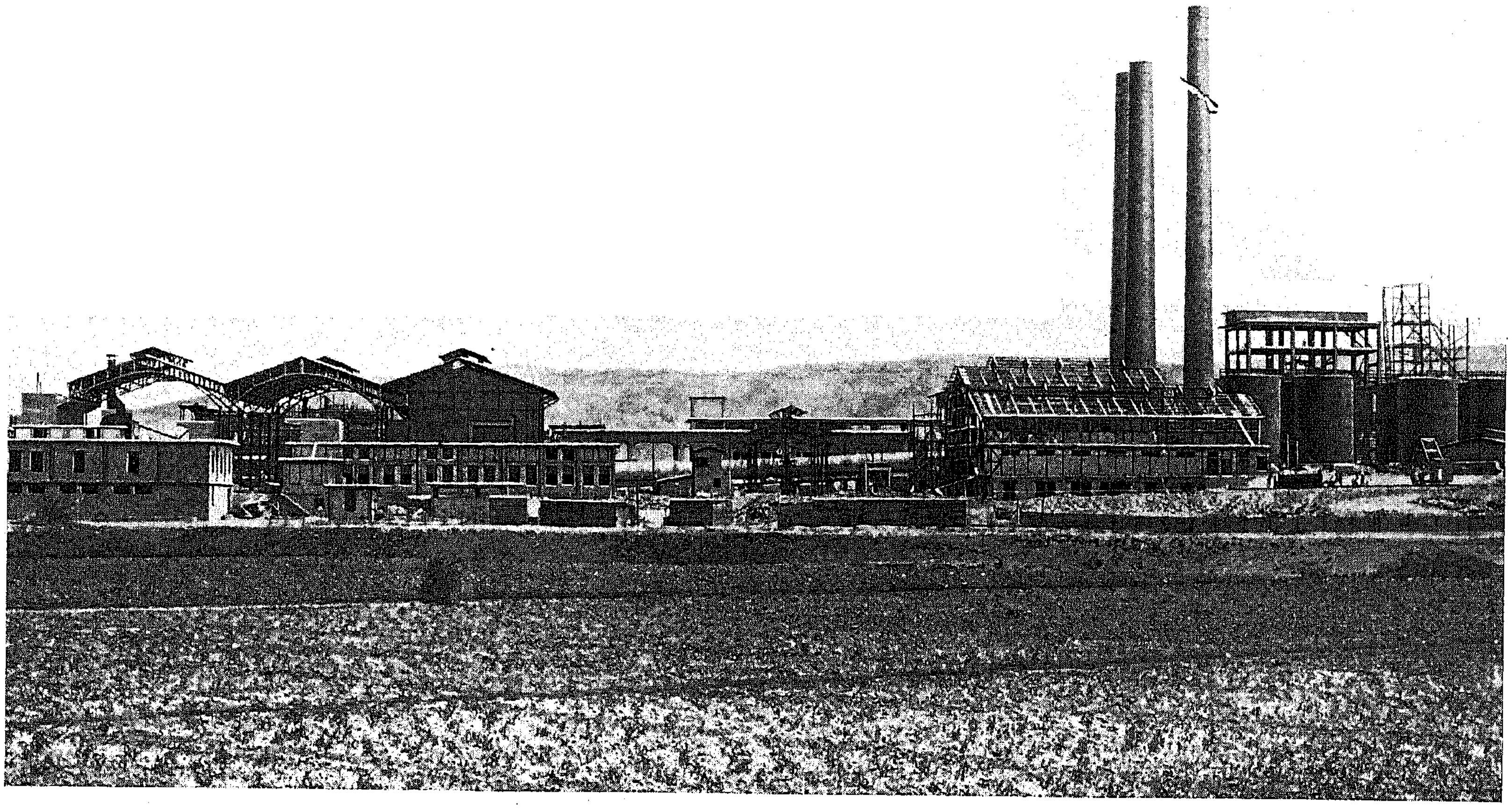
These various power stations, and those of Alexandria and Cairo, in particular, work in conjunction with a number of sub-stations with capacities varying between 500 and 5000 KVA, according to the local requirements, while there are more than 500 distribution centres scattered throughout the town.

The H. T. systems, which have been greatly extended, measure, at the present time, some 100 miles in the case of Cairo, 60 miles for Alexandria and 9 miles for Port Said.

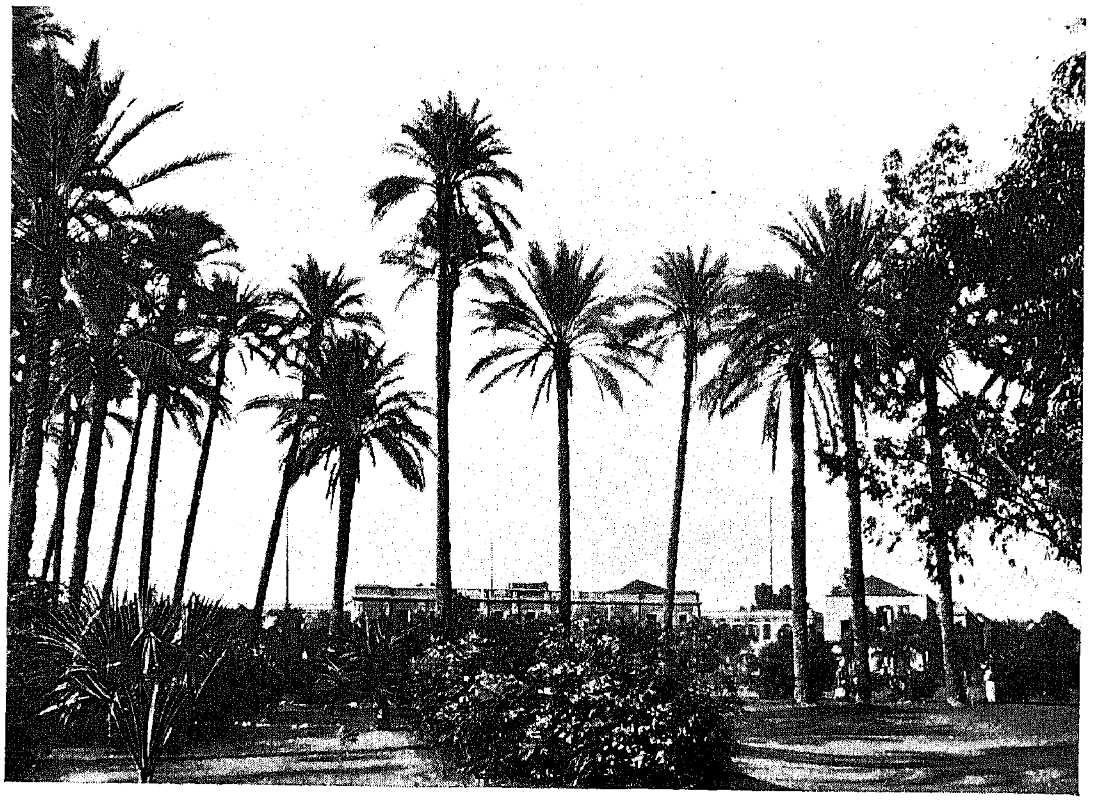
VIEWS OF THE ALEXANDRIA AND CAIRO ELECTRICITY WORKS.







VIEW OF THE POWER STATION OF THE EGYPTIAN PORTLAND CEMENT CO. AT TOURAH WHICH IS NOW IN COURSE OF CONSTRUCTION.

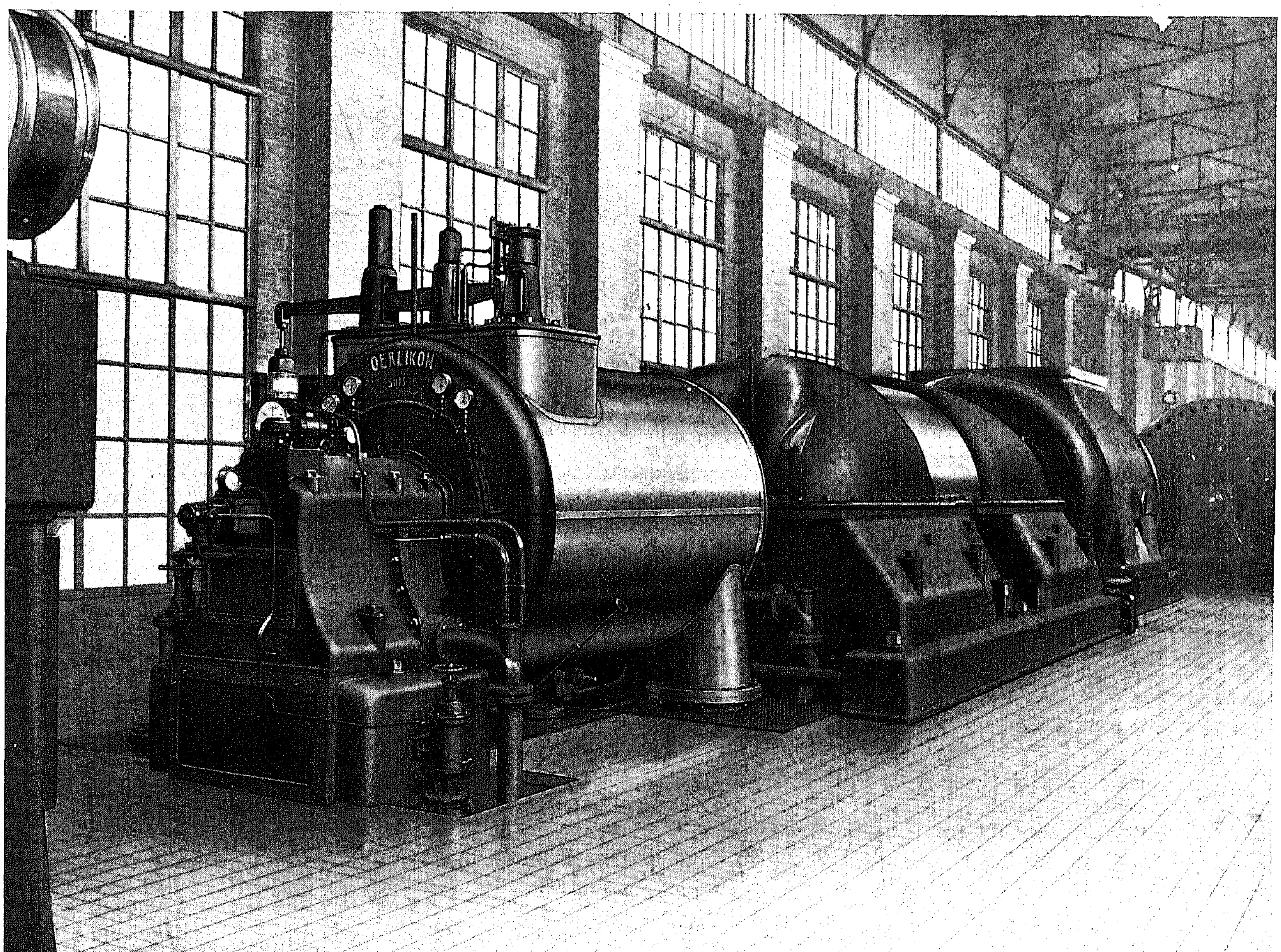


ROYAL SCHOOL OF ENGINEERING, GIZA.

BULLETIN OERLIKON

No. 104 — February 1930

Contents: 15000 KW Oerlikon two-cylinder turbine at the St. Denis power station.
Extension of the range of application of stress calculations made for turbine runners.
Radiation tests on different types of coolers for transformer oil.
Notes and News Items: Oerlikon steam turbines.



15000 KW OERLIKON TWO-CYLINDER TURBINE
IN OPERATION SINCE JANUARY 1927 AT THE ST. DENIS POWER STATION
OF THE SOCIÉTÉ D'ELECTRICITÉ DE PARIS.

Extension of the Range of Application of Stress Calculations made for Turbine Runners.

The usual methods for the calculation of stresses in rotating disc-shaped wheels are based on two differential equations, generally applicable, namely

the equation giving the conditions of equilibrium for an element of disc

$$\sigma_t = x\sigma_r' + \left(1 + x\frac{y'}{y}\right)\sigma_r + \mu\omega^2 x^2 \quad \ldots \quad (1)$$

and the equation expressing the so-called "conditions of compatibility"

$$\sigma_t' - \nu\sigma_r' = (1+\nu)\frac{\sigma_r - \sigma_t}{x} \quad \ldots \quad (2)$$

In these equations, use is made of the following notations:

- x = radial distance between a point and the axis of the disc
- y = thickness of the disc at the point x
- σ_r = radial stress
- σ_t = tangential stress
- μ = specific mass of the material of which the disc is made
- ν = ratio between the so-called "cross-contraction" and the longitudinal expansion
- ω = angular speed corresponding to the speed of disc.

The quantities σ', y' denote differential coefficients with respect to x.

The quantity σ_t can be eliminated from the equation (2) by means of the equation (1). This gives us the following differential equation for r.

$$\sigma_r'' + \frac{1}{x}\left(3 + x\frac{y'}{y}\right)\sigma_r' + \left[\frac{1}{x}(2+\nu)\frac{y'}{y} + \frac{d}{dx}\left(\frac{y'}{y}\right)\right]\sigma_r + (3+\nu)\mu\omega^2 = 0^{*)} \quad \ldots \quad (3)$$

If we introduce in place of σ_r a new function s such that $\sigma_r = \omega^2/\omega_0^2 \times s$, the quantity ω disappears from the equation (3), while the quantity ω_0 comes in its place. This equation then assumes the form

$$s'' + p(x)\,s' + q(x)\,s + (3+\nu)\mu\,\omega_0^2 = 0 \quad \ldots \quad (4)$$

In this differential equation, we replace the quantity x by a new quantity $u = x \times \omega_0$. We thus obtain the equation

$$s'' + p(u)\,s' + q(u)\,s + (3+\nu)\mu = 0 \quad \ldots \quad (5)$$

The differential coefficients are expressed with respect to u.

*) See Stodola: "Steam Turbines" 5th Edition, page 891.

The functions $p(u)$ and $q(u)$ are only governed by the shape of the disc. The integration of the differential equation gives s as a function of u, together with the two quantities s_1, s_2, which represent the so-called "rim conditions".

$$s = f(u\ s_1\ s_2)^{*)}$$

The values σ_1 and σ_2 of radial stresses which represent the limit conditions as regards stresses are, as a rule, prescribed. According to the substitution previously made, we have $s_1 = \frac{\omega_0^2}{\omega_0}\sigma_1$ and $s_2 = \frac{\omega_0^2}{\omega^2}\sigma_2$. The actual stress σ_r is thus

$$\sigma_r = \frac{\omega^2}{\omega_0^2} \times f\left(u, \frac{\omega_0^2}{\omega^2}\sigma_1, \frac{\omega_0^2}{\omega^2}\sigma_2\right) \quad \ldots \quad (6)$$

As soon as σ_r is known, σ_t can be obtained from the equation (1).

The function $f(u, s_1, s_2)$ covers a range which is limited by two values u_1 and u_2 and is, as a rule, dependant upon the shape of the disc. This function does not contain any expression of the manner in which the radial dimensions of the disc have been chosen and of the angular speed upon which the calculations are based; it is thus possible to calculate, in first place, the stresses for a whole series of discs with different radial dimensions, each for an angular speed ω_0 chosen in such a way that the thicknesses of disc can be represented by the same function of u within the same limits $u_1 < u < u_2$. The stresses s in the disc then vary from case to case with the rim conditions; it can easily be seen from equation (6) how the actual rim stresses σ_1, σ_2 are to be introduced into the calculations and how the transition to the actual angular speed (or speed in rpm) is effected.

The discs must have a similarity in shape such that the ratio between the thicknesses at the points $x = \frac{u}{\omega_0}$ of the disc to be calculated and those at the points u of the known disc remains constant [the fact of increasing the thickness of a disc in a proportional way does not have any effect on the mode of variation of stresses, as can be seen from equation (1)].

*) Reference is made to the substitution of x by u by Stodola in "Steam Turbines" 5th Edition, page 340.

We shall illustrate the above by an example, in order to make the matter clearer.

Fig. 1 represents the section of a turbine runner (a) along a diameter. This runner is intended for a speed of 3000 RPM. If the peripheral speed corresponding to this speed of 3000 RPM is calculated for a number of points in the section of the disc, and the thickness is plotted as a function of u, we obtain a shape of disc as shown in b in Fig. 2. Two pairs of curves have been plotted for this disc: first of all, curves giving the radial and tangential stresses s_μ and t_μ for the case where there are centrifugal forces and the specific mass is μ, and secondly, curves representing the stresses s_0, t_0 for the case where $\mu = 0$, in which case the stresses only depend upon the rim conditions. For the purpose of the calculations, use has been made of Grammel's method*), with u as variable quantity, the stresses for an element of disc of constant thickness being obtained by means of the equations

$$\sigma_r = A - \frac{B}{u^2} - \mu\left(\frac{3+\nu}{8}\right) u^2$$

$$\sigma_t = A + \frac{B}{u^2} - \mu\left(\frac{1+3\nu}{8}\right) u^2 \quad . \quad . \quad . \quad . \quad (7)$$

*) See Stodola, "Steam Turbines", 6th Edition, Appendix, page 14.

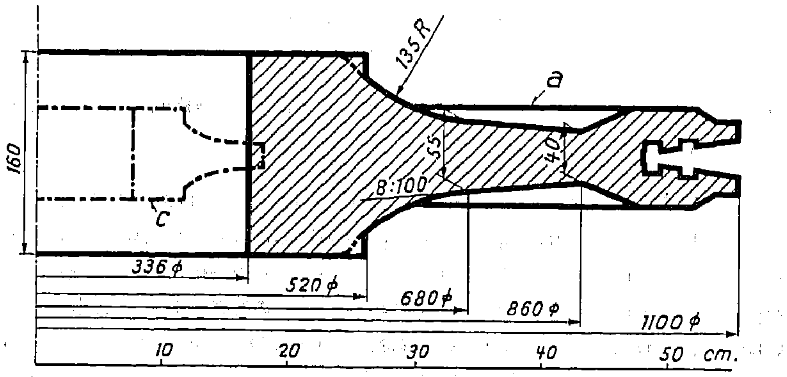


Fig. 1.

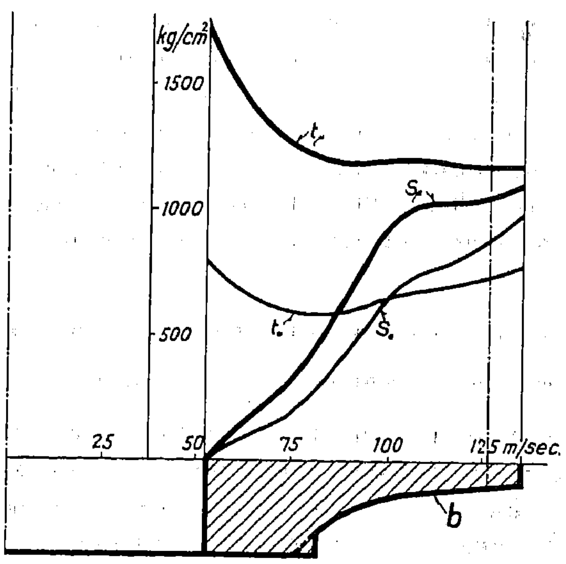


Fig. 2.

The radial stress at the bore of hub is taken as being zero. The assumption that $\mu = 0$ is in accordance with the well-known device suggested by Mises, of introducing in the calculations stresses which can be superimposed and are independant of the centrifugal forces (to set down $\omega = 0$ would be meaningless when the stresses are referred to the variable quantity u).

We now propose to design a runner for 7000 RPM, having the prescribed diameters of 360 mm at rim and 150 mm at bore. The section of disc will have approximately the shape drawn in c in Fig. 1.

The stress at rim has been calculated by means of the usual rim formulae, the value obtained being $\sigma_2 = 550$ kg/cm².

We choose, in first place, as speed for the disc $n_0 = 6720$, corresponding to an angular speed $\omega = 704$/sec.; this gives us as peripheral speeds at rim and bore, $u_1 = 52.8$ m/sec. and $u_2 = 126.5$ m/sec., respectively. We know, however, for this range of peripheral speed, the mode of variation of the stresses in a disc having the shape b. In view of this, we shall simply take, once more, this shape of disc, and all that has to be done is to re-calculate the values of stresses by means of the equation (6); furthermore, we shall confine ourselves to the calculation of stresses at the points where the latter are greatest. The actual speed of 7000 RPM corresponds to an angular speed $\omega = 733$. We have

$$s_2 = \left(\frac{704}{733}\right)^2 \times 550 = 508 \ \text{kg/cm}^2.$$

The values of stresses given by the curves in question are, therefore, to be superimposed in such a way that

$$s_2 = \left\{ s_\mu + k \times s_0 \right\}_{u=126.5}$$

The following table contains the results of the calculations:

u m/sec	s_μ	t_μ	s_0	t_0	s	t	σ_r	σ_t	x_m
52.8	0	1725	0	800	0	1245	0	1350	0.075
126.5	1100	1175	985	780	508	706	550	765	0.180

The superimposition factor is $k = -0.601$. The maximum stresses occur at the bore where the value of tangential stress increases to 1350 kg/cm².

Radiation tests on different types of coolers for transformer oil.

Figs. 1a—1c, 2a—2d, 3a—3b represent three coolers, such as used for cooling transformer oil. It is proposed to ascertain which of these 3 coolers is most efficient in transmitting the heat to the surrounding air, that is to say, to determine how many cm² of outer surface are necessary to lead away 1 watt.

The arrangement adopted for the tests is shown in Figs. 4a—b. The cooler, 1, is connected to a length of pipe, 2, with an inner diameter of 250 mm, containing electric heating coils arranged along half its length. Forced oil circulation is ensured by a Sulzer pump, 3, direct coupled to an electric motor, 4. A Schmid integrating meter, 5, and a flow indicator, 6, are provided in the pressure pipe after the pump. A sluice valve, 7, is fitted at the bottom of the pipe, 2; this valve is closed when working with the circulating pump and open for natural oil circulation. In the case of the latter mode of operation, the valves 8 and 9, in the suction and pressure pipe of the pump are closed. The whole system is filled with thin transformer oil. A length of pipe, 10, is provided at the top, in order to permit of the expansion of oil, due to heating. When working with the circulating pump, the oil leaving the cooler through the lower branch flows through the suction pipe, 11, into the pump, 3, then through the pressure pipe, 12, to the meter, 5, and to the flow indicator, 6; it then penetrates into the heating pipe, 2, leaves the latter at the top and from there returns to the cooler (4 above).

The temperature of the oil was measured at three points t_1, t_2, t_3, by means of thermometers calibrated to $^1/_{10}$ °C. In order to be able to determine accurately the heat radiation of the heating pipe, 2, itself, readings were taken of the external metal temperature at the points t_4, $t_4{}^1/_2$, t_5 and t_6. The temperature of air was measured at a distance of about 500 mm from the heating pipe at t_7, t_8 and t_9. The temperature of the air rising from the cooler was measured during the tests, by means of the same thermometer, at various points. The room temperature was ascertained at a distance of about 5 metres from the testing installation. The heating coils were made up of three star-connected units fed direct from the system. Readings were taken of the supply pressure and current in one phase.

In the case of Fig. 4b, the cooler is fitted with a wooden screen in order to limit the circulation of air. This arrangement is necessary, as, in practice, a large number of such coolers are grouped together so as to form a complete equipment with the result that the air can only gain access from below the cooler. In first place, the radiation of the heating pipe was determined at various temperatures. The radiation of the pump and of the pipe connections was likewise determined, so as to permit of the determination of the actual radiation factor of the cooler.

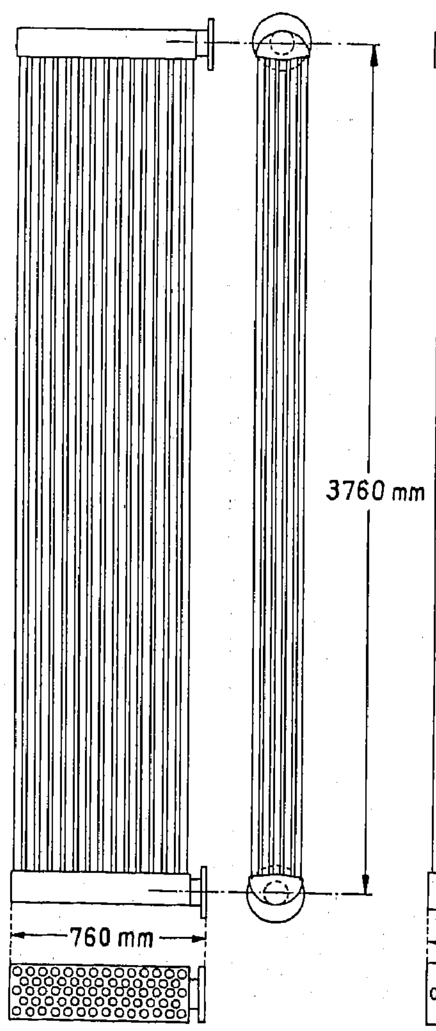


Fig. 1 *a-c.*

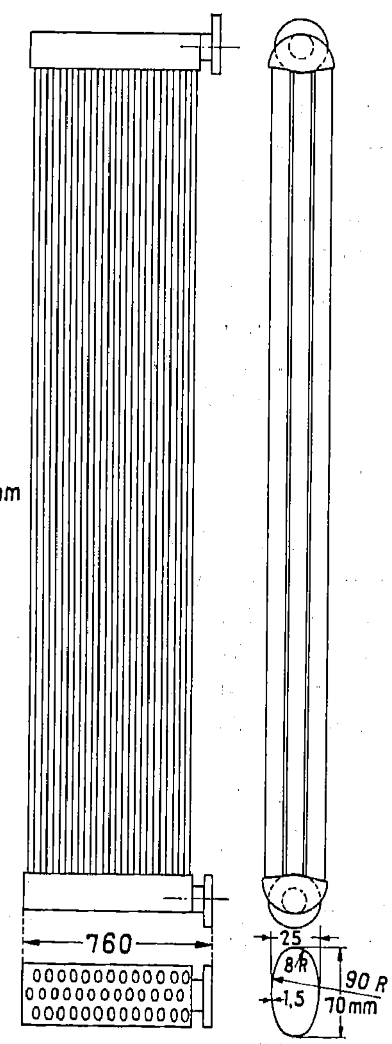


Fig. 2 *a-d.*

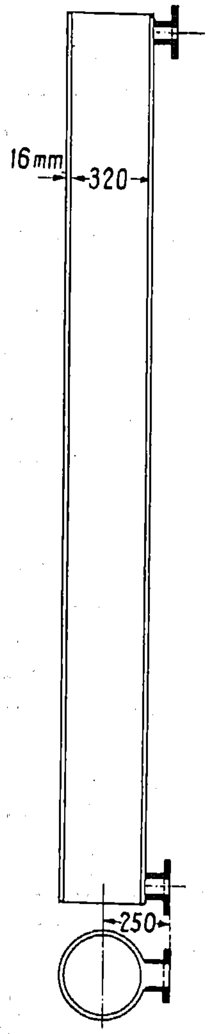


Fig. 3 *a-b.*

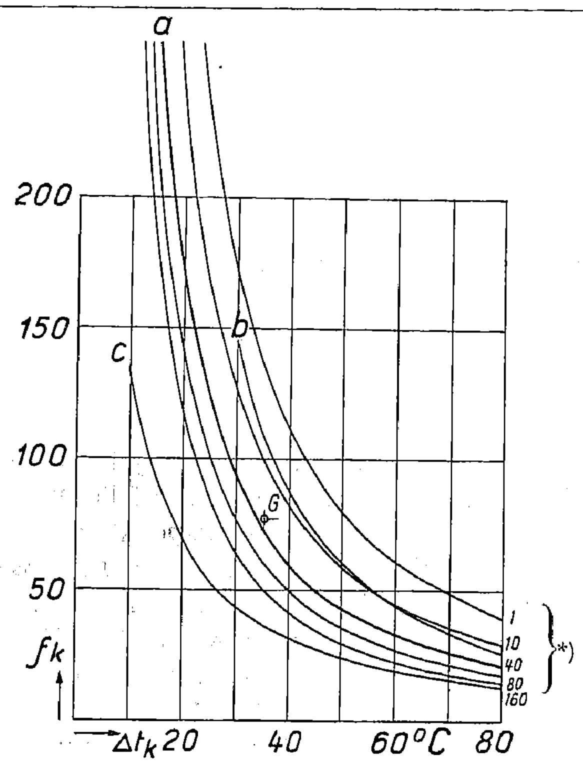


Fig. 5. Surface f_k, in cm², required in the case of the cooler in Fig. 1, for various differences in temperature Δt_k between oil and air at inlet, for dissipating 1 watt, the cooler being operated with natural air circulation and being provided with screen.
Curve *a* = with forced oil circulation of 40 litres (standard).
Curve *b* = with natural oil circulation and with heating elements below.
Curve *c* = for heating pipe.

*) Quantity of circulating oil, in litres/min.

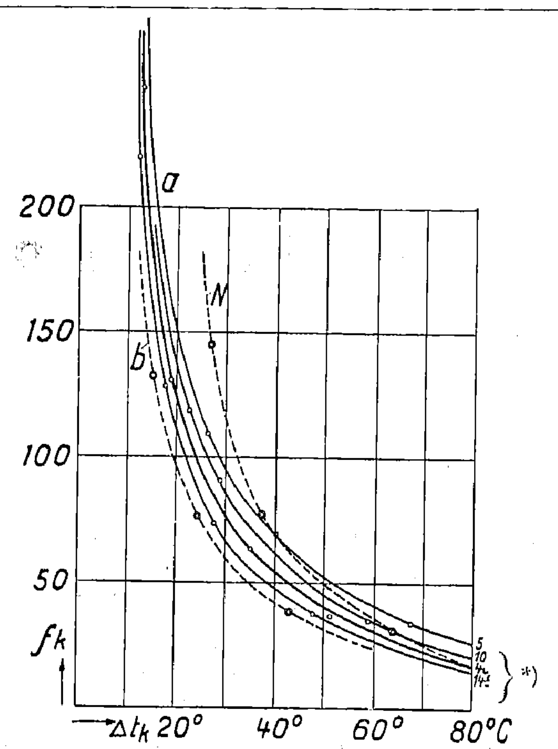


Fig. 6. Surface f_k, in cm², required in the case of the cooler in Fig. 2, for various differences in temperature Δt_k between oil and air at inlet, for dissipating 1 watt, the cooler being operated with natural air circulation and being provided with screen.
Curve *a* = with forced oil circulation of 40 litres (standard).
Curve *b* = with forced oil circulation of 40 litres (standard), but without screen.

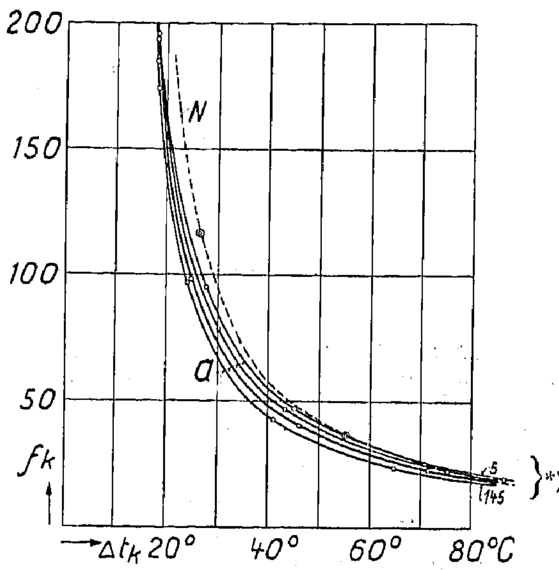


Fig. 7. Surface f_k, in cm², required in the case of the cooler in Fig. 3, for various differences in temperature Δt_k between oil and air at inlet, for dissipating 1 watt, the cooler being operated with natural air circulation and being provided with screen.
Curve *a* = with forced oil circulation of 145, 40 (standard), 10 and 5 litres.

Curve *N* = with natural oil circulation and with heating elements below.

The test results are plotted in Fig. 5 in the form of curves for the cooler represented in Fig. 1. The cooler in question consists of 68 vertical iron tubes, circular in section, with an outer diameter of 30 mm and an inner diameter of 27 mm. The tubes are welded at either extremity to an end plate and a sheet iron cover is fitted over the latter so as to form a small chamber, branches being provided for the inlet and outlet of oil.

In Fig. 5, the quantity f_k represents the number of cm² of outer surface which is necessary in order to dissipate 1 watt. The quantity Δt_k is the difference in temperature between the oil and the air at inlet. The curve *a* is for the normal oil quantity of 40 litres per minute. The curve *b* is for natural oil circulation. The quantity f_k was also determined for the heating pipe itself and is represented in curve *c*. The test results for the cooler in Fig. 2 are plotted in Fig. 6 and those for the cooler in Fig. 3, in Fig. 7.

We only propose to give here a few comparative figures obtained for the three coolers represented in Figs. 1, 2 and 3. The curves in Fig. 8 give the test results for the

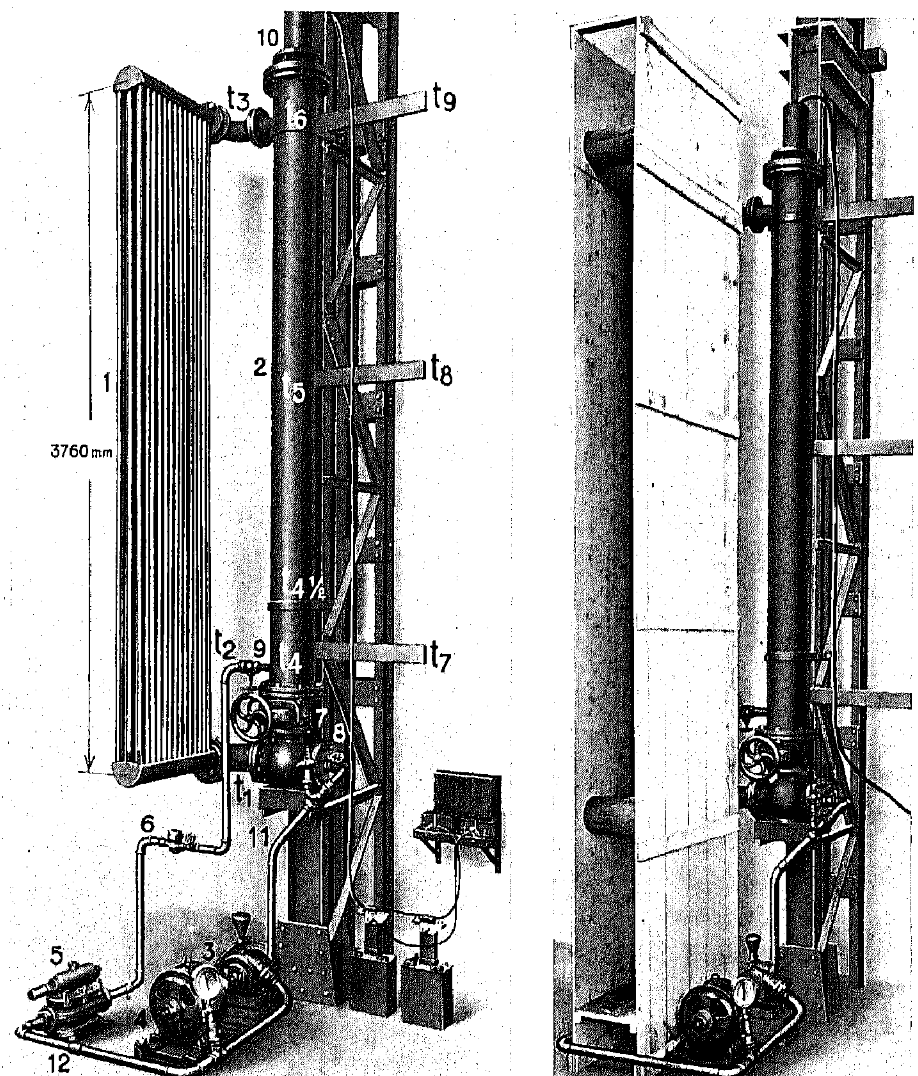


Fig. 4*a*—*b*. Testing installation. Cooler without and with screen.

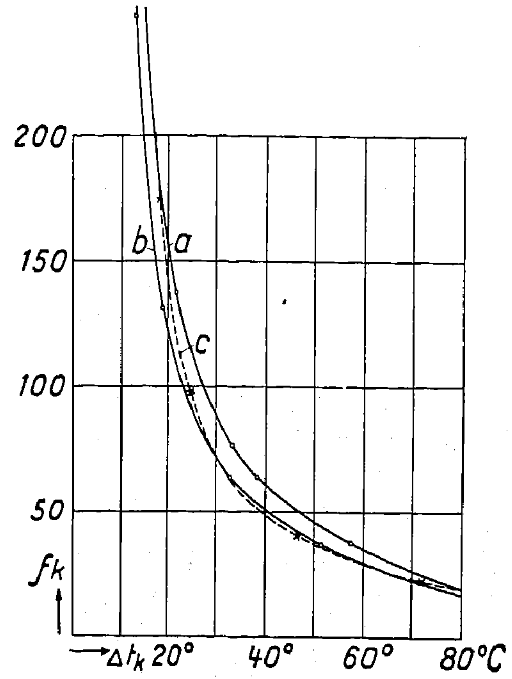


Fig. 8. Surface f_k, in cm², required for various differences in temperature Δt_k between oil and air at inlet for dissipating 1 watt, the cooler being operated with natural oil circulation of 40 litres (standard) and being provided with screen.
Curve *a* = in the case of cooler in Fig. 1.
Curve *b* = in the case of cooler in Fig. 2.
Curve *c* = in the case of cooler in Fig. 3.

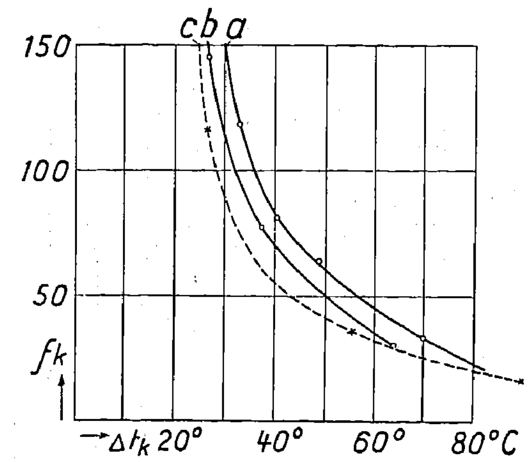


Fig. 9. Surface f_k, in cm², required for various differences in temperature Δt_k between oil and air at inlet for dissipating 1 watt, the cooler being operated with natural air and oil circulation and being provided with screen.
Curve *a* = in the case of cooler in Fig. 1.
Curve *b* = in the case of cooler in Fig. 2.
Curve *c* = in the case of cooler in Fig. 3.

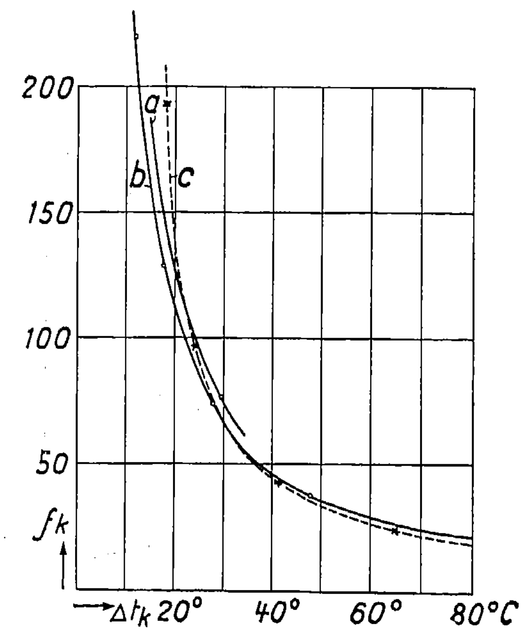


Fig. 10. Surface f_k, in cm², required for various differences in temperature Δt_k between oil and air at inlet for dissipating 1 watt, the cooler being operated with natural air circulation, but with a large quantity of oil (150 litres).
Curve *a* = in the case of cooler in Fig. 1.
Curve *b* = in the case of cooler in Fig. 2.
Curve *c* = in the case of cooler in Fig. 3.

three coolers under normal working conditions, that is to say, with a quantity of circulating oil of 40 litres per minute. The cooler in Fig. 2 with tubes having an oval section and the cylindrical cooler in Fig. 3 are nearly equivalent as regards effect, over the range $\Delta t_k = 30°$ to 70°C. The cooler in Fig. 1 with tubes having a circular section is much less efficient.

In the case of natural oil circulation (Fig. 9), the results obtained for the three coolers differ from each other rather much. The best of the three is the cylindrical cooler, owing to the fact that the resistance to the flow of oil is smaller for this type of cooler than for the other two coolers.

These results are, however, to be applied with caution, for this reason:— The oil circulation depends upon the arrangement of the heating elements. In the case of all tests, the heating elements were arranged in the lower portion of the heating pipe. This had the effect of giving to practically the whole column of oil in the heating pipe, a smaller specific weight than in the cooler itself. As a result, the conditions were more favourable for the natural circulation of oil. In the present case, the object was, in fact, merely to ascertain the relative difference as regards effect of the three coolers, and the arrangement adopted for the tests was the best for this particular purpose.

The curves in Fig. 10 show the influence of the cooling air. If a very large quantity of oil is driven through the cooler, the oil and metal temperatures get more and more similar, that is to say, the temperature drop between oil and metal becomes very small and can then be neglected. There remains, therefore, only the temperature drop between metal and air. For $\Delta t_k = 30°$ C, the cooler with tubes having an oval section is equivalent to the cylindrical cooler. For $\Delta t_k > 30°$ C, the cylindrical cooler gives better results.

The following general rules can be laid down for the designing of coolers for transformer oil:—

A) When the oil is forced through the cooler by means of a pump and the cooling air circulates merely as a result of the natural buoyancy of warm air, the cooler should be designed as follows:—

1. The sections of oil should be as small as possible, that is to say, a small diameter of tube should be adopted.
2. The tubes should be arranged as far apart as possible, so that the flow of air should only meet with little resistance.

B) When the oil and the air circulate merely as a result of their natural buoyancy when warm, the cooler should be designed as follows:—

3. The diameter of tubes should be as large as possible (not less than 30 mm. inner diameter), in order that the flow of oil should meet with as little resistance as possible in the tube. As the diameter of tube increases, the section of oil flowing through the tube becomes, however, greater, and, above a certain diameter, the section of oil does no longer get cooled throughout. As a result, the specific weight of the column of oil decreases and the oil circulation is slowed down.
The diameter of tube required in order to obtain the most favourable results should still be determined by tests.
4. The tubes are to be arranged as far apart as possible so that the air should be able to flow past with as little hindrance as possible.

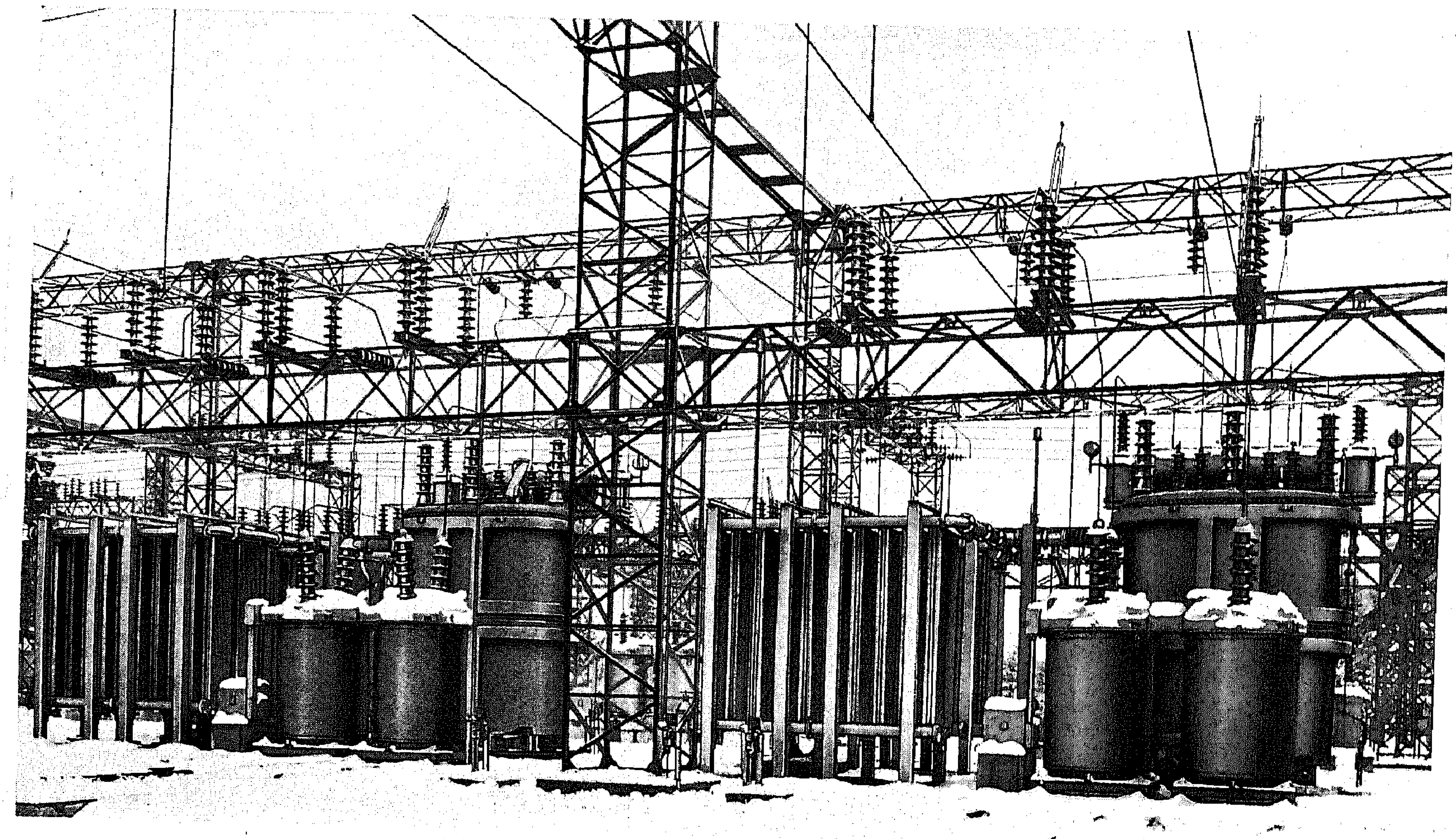


Fig. 11. 9000 KVA. single-phase transformers with stationary oil coolers.

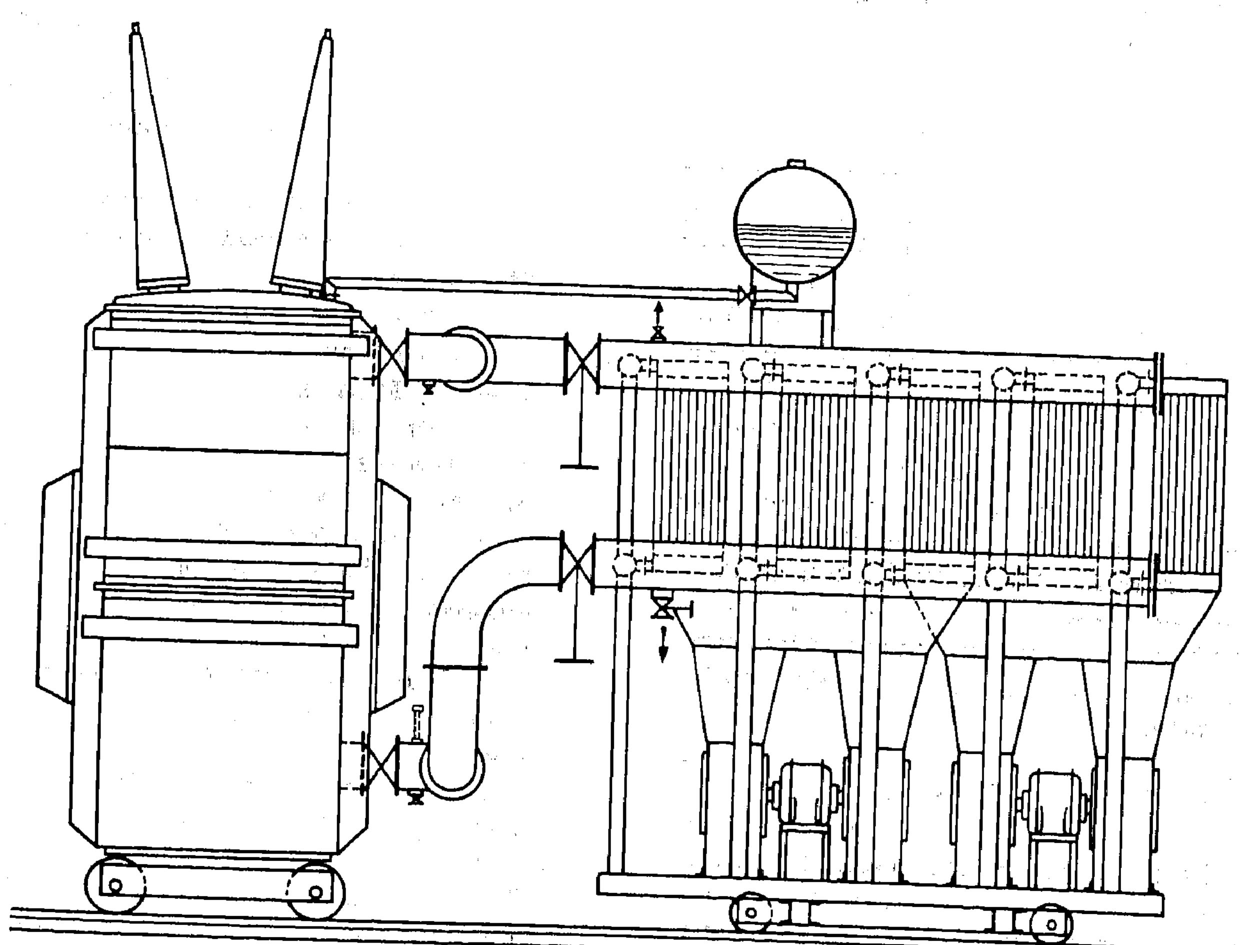
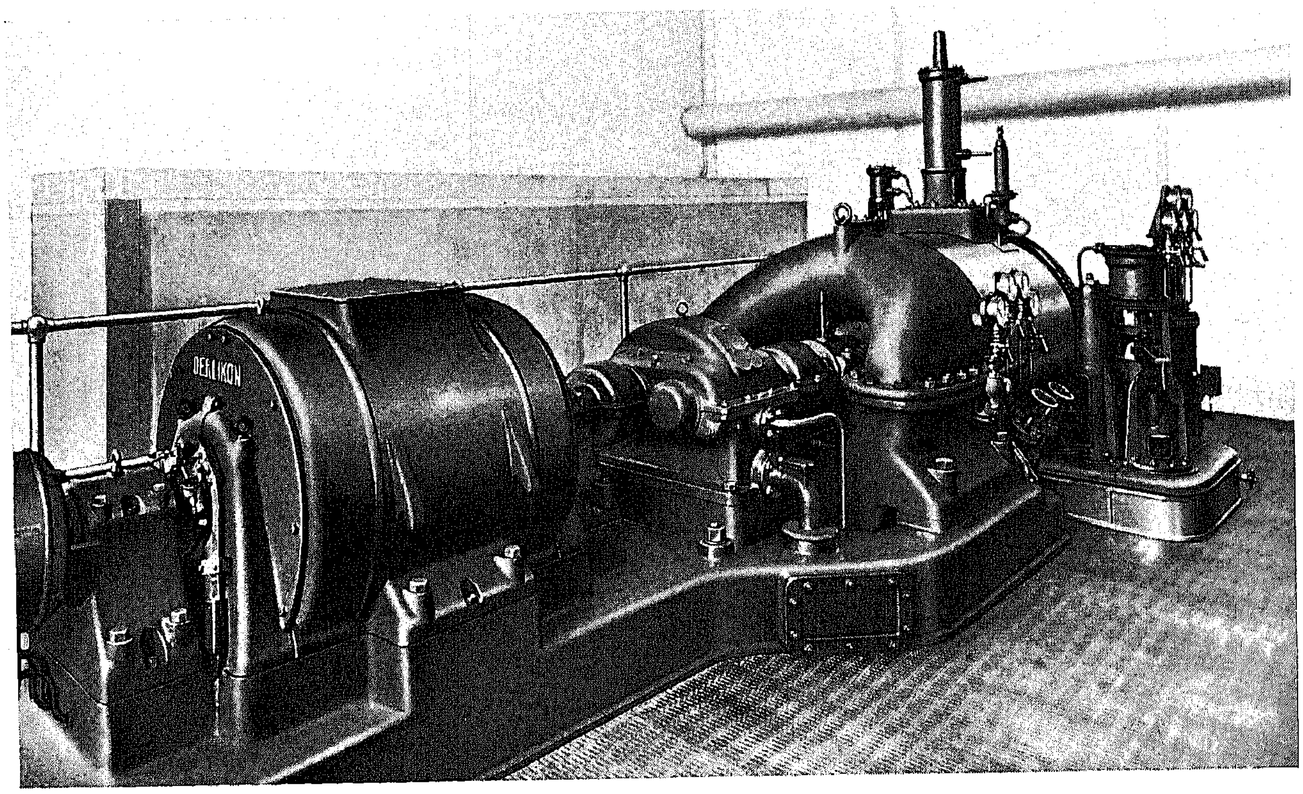


Fig. 12. Drawing showing arrangement of a 12000 KVA. single-phase transformer with displaceable oil cooler equipment.

NOTES AND NEWS ITEMS.



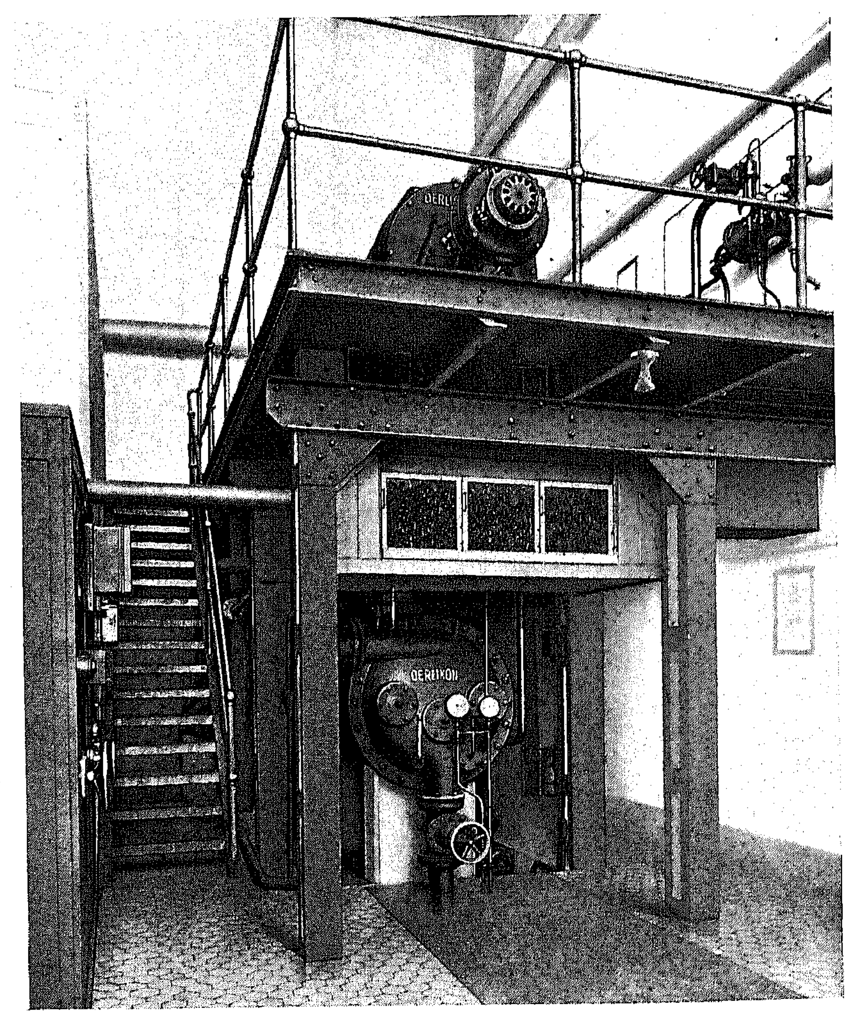
Oerlikon Steam Turbines. The top illustration represents a 460 KW Oerlikon turbo-generator set installed at the power station of the Swiss Industrial Co., Neuhausen. The turbine runs at 7700 RPM and drives, through reduction gear, a three-phase generator at 3000 RPM. The turbine is built as a pass-out turbine and supplies, in winter, the heating steam required for the factory. The illustration on the right shows the lightness of construction of the machine room and the arrangement of surface condenser. The installation was put into service in October 1929.

Even small installations such as that described, where the plant serves for the supply of power and of heating steam, work very economically and compare favourably with installations where the current is drawn from another source and the heating steam is generated separately. The service is still more economical when it is not only the pass-out steam that is used for heating purposes but also the cooling water from the condenser. This is, for instance, the case at the factory of the Seta Bemberg in Gozzano where two 800 KW Oerlikon turbo-generator sets are in operation, the second one having been put into service in the spring of 1929.

The possibility of working, at the present day, with considerably higher boiler pressures has led to a still wider application of back pressure turbines. When it is a case of dealing with large quantities of steam, these machines operate with a very high thermo-dynamic efficiency. An 850 KW Oerlikon back pressure turbine for 480 lbs/sq. in. (gauge) has been in operation since May 1929 at the Widnau Power Station of the Swiss Viscose Co., Emmenbruecke.

The supply of steam for industrial purposes in conjunction with the generation of power has, at the present day, become a feature even of large power stations. The Oerlikon Company have received an order for a 14000 KW turbine for the City of Leicester, which is to work at a pressure of 350 lbs/sq. in. (gauge) and supply 30000 lbs of steam per hour at a pressure of 65 lbs/sq. in. (gauge) for heating purposes.

It is the usual practice in modern steam turbine installations to heat the boiler feed water with pass-out steam from the turbine. In the case of the 75000 HP steam turbine at 3000 RPM, which the Oerlikon Company are building for the St. Denis Power Station of the Société d'Electricité de Paris, the initial pressure will be 765 to 840 lbs/sq. in. (gauge) and the feed water heating will take place up to 355 ^{0} F.



ATELIERS DE CONSTRUCTION OERLIKON, OERLIKON

BULLETIN OERLIKON

No. 105/6 – March/April 1930

Fundamental Principles Underlying the Problem of the Protection of Generators and Transformers.

By H. Puppikofer. *)

I. Necessity for protection and conditions to be fulfilled.

The constant growth in power demand to be dealt with in distribution systems, has necessarily led to the adoption of generating units of increasing capacity. For large units, the capital outlay is relatively - that is to say, per unit of power - smaller. The plant has also a better efficiency so that the service is more economical. The number of machines required for a given output is smaller with such large units, with the result that there is considerable saving and simplification with regard to maintenance.

The capital invested in these machines has, in fact, now become so large that increasing attention is being paid, in general, to the protection of plant. The best safeguard for any electric machine is undoubtedly to dimension it correctly and to adopt a substantial design. In the event of a concourse of unfortunate circumstances, faults can, however, still occur and it is advisable to provide some means of protection against them. A comparison of the cost of a large unit with the cost of a complete selective protection equipment always shows that the protective equipment is more than paid off if it only protects a single time the machine in question against serious damage. Another important consideration is that the industrial consumers, as well as town consumers attach more importance, at the present day, to the continuity of supply. The electric supply company can, in fact, suffer great direct or indirect losses as a result of an interruption in service. The duration of the period during which the generator is out of service depends on the extent of the damage. In cases where serious damage has been done to the iron core, it may be necessary to replace the stampings of the generator - an operation which is long and costly. The limitation of the damage, that is to say, the mitigation of the direct or indirect consequences of a breakdown, is, however, only possible provided the protective relay used comes into play even for small fault currents, amounting to only a fraction of normal current.

An interruption in service is to be gauged not only by the duration of the disturbance in a particular unit; its effects can be further increased momentarily in that the breakdown of the unit in question may lead to the closing down of the sound parts of the installation. The protective relay, must therefore, not only take over the protection of the given machines or parts of installation, they must further cause the faulty parts to be cut out as soon as possible, so that the remaining parts of the system should be able to continue to work undisturbed under all conditions. This isolation of the centre of disturbance is called the "selective effect of the protective relay". Apart from possessing accuracy and sensitiveness, the protective devices used in electric systems must be characterised by absolute reliability as regards selective effect. Furthermore, it must be possible to adjust these devices in such a way that they do not come into operation as a result of the equalisation processes that occur in the case of standard modes of connection. The necessity for a selective effect was realised at an early date. At the present time, however, the consequences of an interruption in the supply of energy have become so far-reaching in effect, in view of the quantities of power dealt with, that the station superintendent must require this particular property of any protective equipment, in very first place.

The foregoing can be summed up by saying that a protective equipment, in order to be useful, should satisfy the following conditions:

1) It must protect the system against faults such as may occur in any part of the system, i. e. the protective relays must have selective properties.
2) It must protect the object in question and the parts of the system themselves, i. e. the protective relays must be sensitive to the smallest faults.
3) In order to fulfil entirely the two above conditions, the protective equipment, i. e. the various protective relays provided, taken as a whole, must be capable of dealing with any fault that may occur.

It has become usual, in recent times, to term selective protection any selectively acting protection. This designation applies, however, only to one property which is common to all protective systems (or should be) and does not represent any actual characteristic. It is, therefore, absolutely necessary that the mode of protection chosen should be described more accurately.

The D. C. pressures used for the field circuit of A. C. generators are so low that, in the case of present-day designs of rotor, faults that are dangerous for the service hardly

*) See also article by the author in the "Bulletin de l'Association Suisse des Electriciens", No. 2, of the 20th January, 1928, dealing with the same matter.

occur. In view of this, it has not been found necessary to devise a mode of protection for the field circuit of generators.

II. Different classes of faults in generators.

The A. C. windings of generators are exposed to internal or external faults. These different kinds of faults are enumerated below, approximately according to their frequency and importance.

Internal faults: 1. Short-circuits between phases
2. Short-circuit to earth
3. Short-circuits between turns
4. Interruptions in conductor

External faults: 5. Rise in pressure as a result of increase in speed
6. Overload

With the exception of interruptions in conductors, all faults can be traced to defects in insulation inside the electric machines. In the case of short-circuits between phases, it is the insulation to earth and, in the case of short-circuits between turns, the insulation between neighbouring turns that breaks down. Interruptions in conductors can occur in badly made coils and terminal connections which can get loose, for instance, as a result of frequent short-circuits. With present-day manufacturing processes, in well-equipped workshops, and with the methods used for supporting coils, this fault is, however, nearly non existent.

It must be said, from the outset, that there is no universal relay such as acts in the case of all the above-mentioned faults. It is, therefore, necessary, whenever the size or the price of the units make this justifiable from an economical point of view, to provide various combinations of relays to ensure full protection. In all cases, the relays chosen must not only cause the release of the oil circuit breaker of the unit in question, but must also de-magnetise it, so that it should not work with its own pressure on the fault.

III. Different modes of protection for generators.

a) Reverse power relay.

For a long time, the use of reverse power relays was regarded as sufficient for the protection of generators working in parallel. The idea underlying this mode of protection is to cause the operation of the protective gear as soon as the power changes direction, that is to say, flows from the system into the generator instead of the other way round. Such a reversal of the direction of flow of power does not, however, take place either in the case of a short-circuit to earth or of a short-circuit between turns, or in the event of an interruption in a conductor. The reverse power relays thus merely provide protection against short-circuits between phases, and do so only in cases where these short-circuits are so severe that they result in a reversal of the direction of flow of power.

Although the methods of measuring power in three-phase systems are generally known, the reverse power relays are even at the present day often suggested and used quite incorrectly. This explains the many bad experiences made nearly everywhere with this protective device. In many cases, two single-pole relays, independent of each other and arranged in accordance with the two-wattmeter method, are used per three-phase generator, while it is entirely forgotten that when the power factor of the system drops below .5 in the inductive range, the torque of relay system changes direction and causes the release of gear, without a fault occuring in the generator.

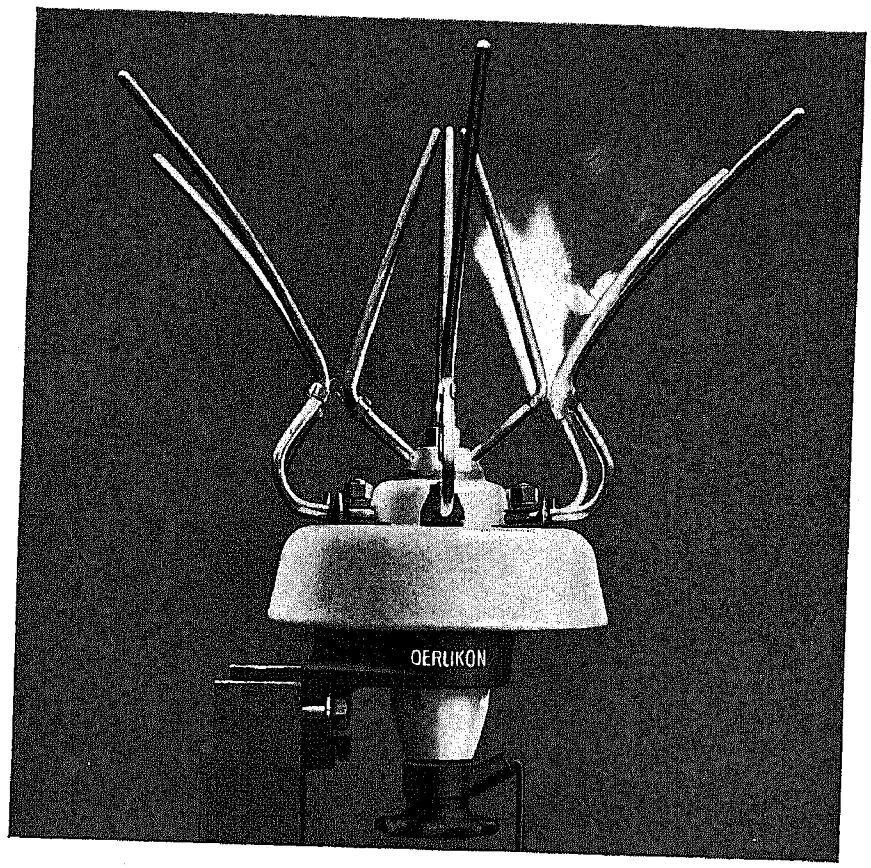
With another solution, a relay is used where the current of one phase is combined with the pressure between the phase in question and the preceding phase in the rotating field. This relay does not give rise to faulty releases of gear as long as the current is in the inductive range. If the phase displacement is in the capacity range and exceeds an angle of 60°, there is, here too, a release of gear at the wrong moment. This characteristic is a hindrance in the case of installations where long overhead transmission lines have to be put under pressure by the generators. There is another drawback common to single-phase reverse power relays: they can no longer produce the necessary torque for the release of gear, when the defect leads to a drop in the phase pressure in question. In order to obtain, at least in all cases where the internal defect is not in the three phases, a sufficient torque in the relay system, an arrangement with two systems has been resorted to where, for the time being, a given current is combined with the pressure between phases at right angles with it. These relays do not lead to any trouble in the case of inductive loads of generator, but, in the case of capacity loads, they cause the release of gear at the wrong instant. When the relay has a small equalisation angle, the faulty release takes place, in fact, even for a small phase displacement in the capacity range.

The arrangement too, where the star-voltages of the three-phase system are applied to three single-pole relays does not lead to the desired result, as in the case of single-phase short-circuits in the system, the torque changes direction in one of the two relay systems in question and this causes also a faulty release.

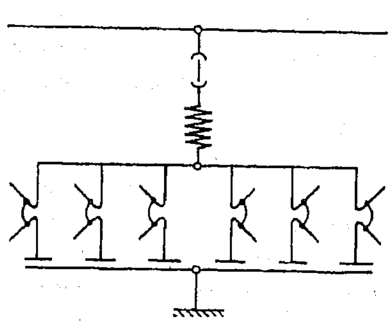
It is only possible to obtain correct reverse power protection for all conditions of service in the case of three-phase current, when use is made of an instrument of the same type as meters with several systems (in the case of non-earthed neutral point, with two systems, in the case of earthed neutral point, with three systems), which are mechanically coupled so that the sum of their torques is always proportional to the energy flowing.

The Oerlikon Company have introduced a considerable improvement in the design of this type of reverse power relay and are taking out a patent in this connection. The ordinary reverse power relays have, for each phase, one disc and two electro-magnets between the poles of which the disc is arranged, one of the magnets being excited by the current and the other by the pressure. In the case of the Oerlikon reverse power relay, the revolving system consists of as many closed loops as phases to be measured (see Fig. 1). One of the two above-mentioned magnets is designed with fully closed magnetic circuit and is linked up with the corresponding loop. The loop acts as short-circuited secondary winding of the magnet. A current is induced in it, which is proportional to the current flowing in the excitation winding of the magnet. This current flows in opposition to the field of the second magnet which is proportional to the other energising current and creates a torque with a direction corresponding to the flow of energy. With this relay, it is possible to obtain a very high degree of sensitiveness with a power consumption of 23 VA in the pressure circuit and 18 VA in the current circuit.

Protection against Surges for Working Pressures up to 3000 volts.



In the case of pressures below 3000 volts, the ordinary horn type protective gear no longer gives any security, as either a large gap (at least 3 to 4 mm) has to be adopted, in order to prevent the welding of the horns when the latter have to deal with heavy currents or, if small gaps are resorted to, the current led away has to be limited to small values by means of resistances. In the former case, the pressure at which the gear operates is very high (6000 to 8000 volts) and in the latter case the power led away is too small to reduce the surge.



With the design evolved by the Oerlikon Company, it is possible to lead away currents of about 100 amps, and to set the gear for as low a pressure of operation as desired. The gear consists essentially of an ohmic resistance in series with a fuse and a discharge device. In the case of surges, the isolating layer of air of the discharge device breaks down, the surge is led to earth and a current of about 100 amps, at working pressure, flows to earth through the fuse, which melts after about half a second, and interrupts the circuit once more. The design adopted by us provides for six discharge devices, each with corresponding fuse in parallel, so that the process can take place six times until the protection is exhausted. Tests have shown that two discharge devices never work simultaneously. As a result of the use of horn type fuses, reliable switching off is ensured and the replacement of fuse wires is facilitated. On the other hand, after all fuses have melted, the gear acts as an ordinary horn type arrester.

The equipment consists of a porcelain insulator with a central core for conducting the surge, terminating in six horns, and of six electrodes passing through the insulator, along the periphery of cup, and each provided with a horn. The electrodes are isolated from the earthing ring by a perforated insulating ring and are fitted with interchangeable copper caps. The series resistance used is a special silite resistance of 5 to 30 ohms, the latter value being dependent upon the pressure; it is built as an integral part of the protective gear. The insulating ring is changed by loosening the screw with hand knob at the bottom of gear and by lifting the upper part of the apparatus. The fuses consist of short silver wires with two small spring terminals made of strips of special bronze, which are fitted directly on to the horns. The equipment in question is weatherproof and is suitable both for outdoor and indoor use.

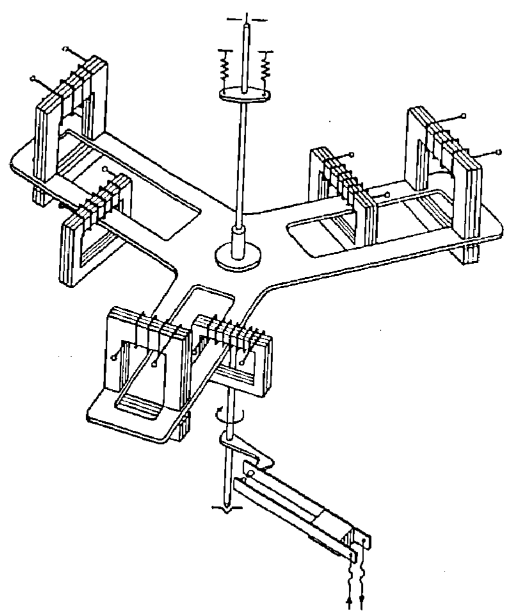


Fig. 1. Simplified perspective drawing of a power direction relay.

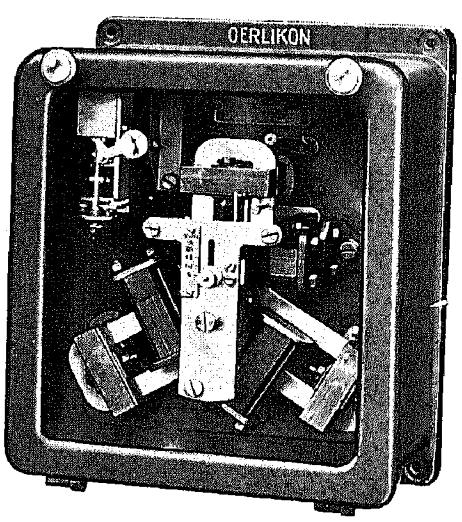
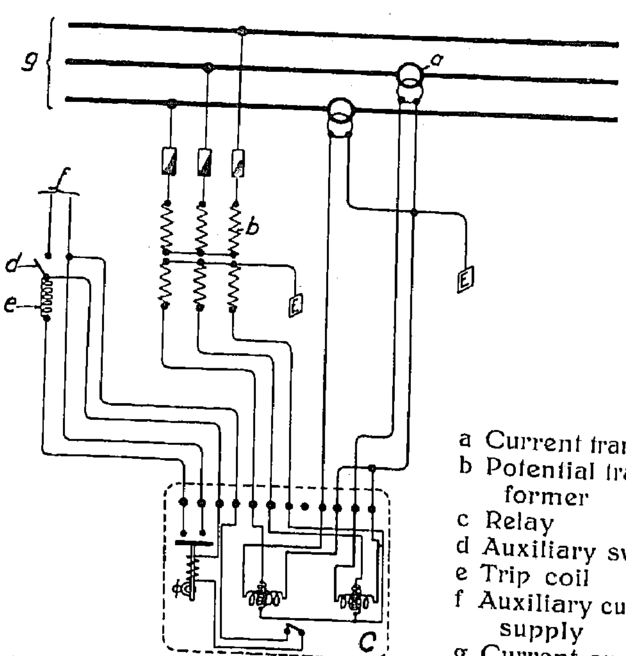
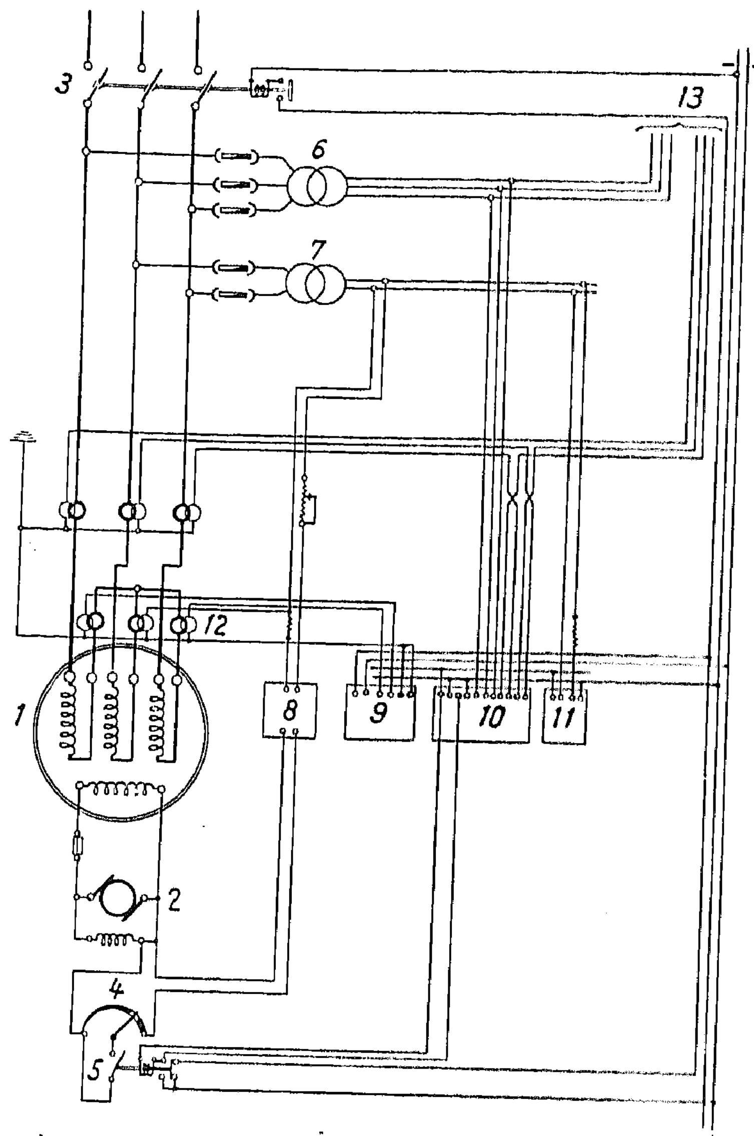


Fig. 2. Triple-pole power direction relay.



a Current transformer
b Potential transformer
c Relay
d Auxiliary switch
e Trip coil
f Auxiliary current supply
g Current supply
e Earth

Fig. 3. Diagram of connection of a double-pole power direction relay.



1 Three-phase generator
2 Exciter
3 Oil switch
4 Shunt regulator
5 Field switch
6 Three-phase potential transformer
7 Single-phase potential transformer
8 Pressure regulator
9 Maximum current relay
10 Reverse power relay
11 Maximum pressure relay
12 Current transformer
13 to the measuring instruments.

Fig. 4. Diagram of connection for the protection of a three-phase generator by means of a power direction relay.

The relay is of flush mounting or projecting pattern (see Figs. 2 and 3). The same relay is also used in conjunction with overload and other relays for the protection of lines and bears the general name of "power direction" relay.

The reverse power relay comes into play only in the case of a class of fault such as referred to under 1) and only when the short-circuit is a severe one. In view of the very limited protective action it affords, this relay is only to be recommended for small generators which work in parallel with others and in cases where it is not desired to make the capital outlay entailed for more far-reaching protection (Fig. 4). In the case of generators working individually, there is no object in providing reverse power protection, as the energy cannot come from any other source.

b) Differential protection.

In the case of generators having a large capacity per unit, it is the general practice, at the present day, to resort, more and more, to differential protection by the Merz-Price method which is based on the comparison of currents. With differential protection, two similar quantities are always compared

and their difference determined. This difference can be arrived at mechanically, magnetically or even electrically. The latter method is given preference, at the present day, as the dimensions of the relay are independent of the rated current of the object protected. The connections are so arranged that, as long as there is no disturbance in the service, the current does not flow through the relay. If a disturbance occurs, the current is forced into the circuit of the relay and causes the operation of the latter. The relays used in this connection are nothing else than maximum current relays of great precision.

In the case of ordinary differential protection, the currents are compared before and after the object to be protected. There are two modes of connection for differential protection: the arrangement with current transformers in series (Fig. 5) and the arrangement with current transformers in parallel (Fig. 6). In the case of the series arrangement, the pilot wires carry

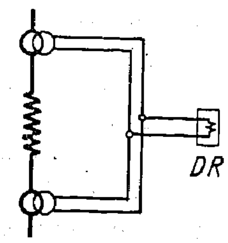


Fig. 5. Differential protection. Series arrangement.

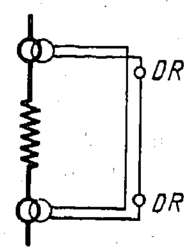


Fig. 6. Differential protection. Parallel arrangement.

current permanently and the differential relay DR is connected across them. In the case of the parallel arrangement, the E. M. F.'s of the current transformers are in opposition; the pilot wires only carry current in the case of disturbances and the relays DR are in series with them. We have thus here, permanently, a case of open current transformers, which conditions are otherwise carefully avoided. The current transformers must, therefore, be specially designed as actual series transformers. The series arrangement of current transformers is used for the protection of individual objects, such as generators and transformers, the parallel arrangement, for the protection of lines.

The differential protection, in view of the principle on which it is based, works absolutely selectively; it looks after the portion of the system which is situated between the two current transformers. As it is not an overload but a balanced load protection, the operating current can be reduced to a fraction of the rated current.

In the case of differential protection, it is necessary to have 6 current transformers and 1 triple-pole differential relay, while, for reverse power protection of a generator, 2 current transformers, 2 potential transformers and 1 double-pole reverse power relay are required. Differential protection is thus undoubtedly more expensive and somewhat more complicated. On the other hand, it can also be used for machines working alone. Furthermore, it retains its absolute selective effect, even in the case of the lowest pressure, and can, finally, also protect the plant against short-circuits to earth, provided the neutral point is earthed. The differential relay, when connected in the usual way, does not operate in the case of short-circuits between turns and of interruptions in conductors. When a generator works in conjunction with a transformer, the earthing of the neutral point through a low ohmic resistance protects the machine against H. T. charges due to the transformer. If the generator works directly on the middle pressure system, that is to say, without the insertion of a transformer, the H. T. phenomena that occur when a short-circuit to earth ceases are effectively prevented by earthing the neutral point, and the static charges of this system are led away continuously. Endeavours have already been made, in such cases, to obtain an automatic selection of the outgoing circuits from the generator busbars, affected by the short-circuit to earth. For this purpose, it is only necessary to dimension the earthing resistance in such a way that the current flowing to earth at the place of the earth is sufficient to cause the operation of the maximum current relay, even of outgoing circuits carrying the largest current. Of course, all line circuit breakers must then be provided with a maximum current protection in each phase. When dimensioning the earthing resistance serving for this object, it is necessary to see that the current of the short-circuit to earth that flows to earth by way of the arc, in the

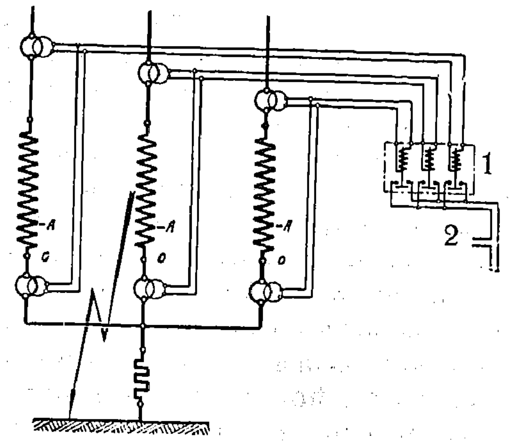


Fig. 7. Protection against short-circuits to earth by means of a differential relay, in the case of a system with earthed neutral point.
1 Differential relay.
2 to the tripping device of the generator circuit breaker and of the field switch.

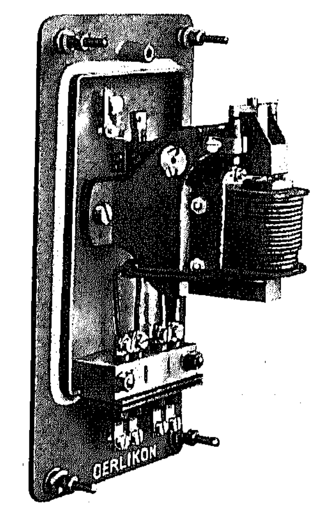


Fig. 8. Differential relay for letting into panel, viewed from the back.

event of faults in the generator itself, does not reach values for which too great damage may result.

In modern power station operation, it is the general rule to distribute the service over a number of independent self-contained units which can be termed "service units". If it is necessary to step up the generator pressure for transmission purposes, the best arrangement is to have transformers with the same capacity per unit as the generators. Generators and transformers can then be grouped together and permanently connected without insertion of circuit breakers and L. T. busbars between the two. The generator then forms with the corresponding transformer a service unit, the only circuit breaker provided being on the H. T. side of the transformer. In this way, the cost of installation is considerably reduced and the service is simplified. If each generator works with its corresponding transformer, the problem of dimensioning the earthing resistance can be regarded from two points of view. One superintendent may desire great sensitiveness of the differential protection, with regard to short-circuits to earth, so that the latter should be interrupted instantaneously by the relay at the very moment they occur; another superintendent may wish to keep the earth current in the generator small, so that in the case of short-circuits to earth, the damage should be limited as far as possible. In the former case, a low ohmic earthing resistance has to be provided, while in the latter case a high ohmic earthing resistance is required. The diagram of connections in Fig. 7 shows a generator which is to be protected by

a differential relay. Let us assume that the neutral point of the generator is earthed through an ohmic resistance which is dimensioned in such a way, that the earth current never exceeds the value of the normal current, even in the case of full pressure. We further assume that the current transformers are for the normal secondary current of 5 amps., and that the differential relays are so adjusted that they come into play in the case of a difference in current of .5 amps = 10% of the rated current of the current transformers. The differential relay will cause the release of circuit breaker, in the case of a short-circuit to earth, when the earth current reaches a value equal to 10% of the normal generator current. If we leave out of account the resistance of the earthing arc and of the earth conductor, the pressure applied to the resistance will have to amount to 10% of the normal pressure, in order to produce the necessary earth current for the release. If the length OA represents 10% of the length of winding of a generator phase, it can be seen at once that a short-circuit to earth between the neutral point O and the point A cannot cause the operation of the differential protection, which means that the 10% of winding on the side of the neutral point is not protected against short-circuits to earth. It must be emphasized, however, that these parts of the winding are just those that have, during normal service, the smallest potential to earth, and, as the insulation of the windings is kept the same everywhere, a short-circuit to earth is hardly to be expected there. An increase of the earthing resistance results in the proportional increase of the unprotected part of winding and means a lesser degree of sensitiveness of the differential protection. On the other hand, it is possible, while retaining the same earthing resistance, to reduce the unprotected part of winding by increasing the sensitiveness of the differential relay. This can be done by using, with the same relays, current transformers for a higher secondary current, for instance 10 amps., or better still by using, with the same current transformers, more sensitive relays which, for instance, come into play for a difference in current of .1 amp instead of .5 amp. The effect of increasing the earthing resistance can then be compensated, to a certain extent, through the choice of the relay, so that the solution is a compromise which has to take into account the wishes of the superintendent. It can, however, be said that, when the generators are connected directly to the corresponding transformers, the earth capacity of the plant electrically connected to the generator is so small that the earthing current cannot cause any appreciable damage. In view of this, too great sensitiveness should not be required of the differential protection, with regard to short-circuits to earth. It is further sufficient, instead of arranging for the closing down of the circuit in question, to provide for the sounding of a signal. It is even possible to dispense entirely with differential protection against short-circuits to earth by differential relays and to provide an earth relay (maximum current relay) in the earth wire, after the high ohmic resistance, which causes the operation of a bell in the case of a short-circuit to earth. The same object can also be attained without earthing resistance by measuring the potential of the neutral point of the generator to earth and by arranging for the operation of a signal by a pressure relay.

In cases where the generators are not directly connected to the corresponding transformers, an arrangement can be adopted, with advantage, where the neutral point is earthed, combining a differential relay and an earth relay. The differential relay acts only in the case of short-circuits to earth inside the generator; it acts entirely selectively. The earth relay, on the other hand, acts in the case of all short-circuits to earth in the plant connected electrically to the generator.

This property of the ordinary earth relay can be used to provide, apart from generator protection, also protection for the bus-bars and the switchgear installation at generator pressure against short-circuits to earth. A maximum current relay with time lag is inserted in the earth wire, so that this relay acts only after the differential relay, which latter comes into play instantaneously. On the other hand, the current setting can be chosen much higher than that corresponding to the sensitiveness of the differential relay to short-circuits to earth; this can be done owing to the fact that the parts of the installation external to the generator, that are to be protected against short-circuits to earth, consist mainly of conductor material which is not as sensitive as the generator winding itself and do not include so expensive parts. The solution which is to be given preference is that where the same differential relay has to protect all parts of the installation at generator pressure. The current transformers for the differential protection can then be arranged close to the generators and can even be designed as bushing transformers and mounted on the bushings of the generators. These bushing transformers can then also be provided with a second core of which the secondary winding serves for supplying the current for the compensation of the pressure regulator and for feeding the overload limiting device. In this way, it is possible to ensure that the protective device comes into operation in the case of all short-circuits external to the generator.

If various generators, with earthed neutral point, work in parallel on the same busbar system, without interposition of transformers, the resistance of the circuit through which the short-circuit current has to flow back, in the event of a short-circuit to earth, differs according to the number of machines in service. The problem of dimensioning these resistances in such a way as to ensure the highest degree of sensitiveness of protective gear and to reduce to the smallest limits the damage resulting from the arc of the short-circuit to earth, is thus rendered very much more difficult. In this case, it is advisable to have the neutral points of the machines insulated and to provide another path through which the current of the short-circuit to earth can flow back. The simplest arrangement is to use for the purpose the neutral point of a transformer, for instance of the station transformer, of which the secondary winding is delta-connected. The resistance between the neutral point of the transformer and earth is then dimensioned in the same manner as when earthing a single generator. The windings of the transformer must, of course, be capable of carrying the maximum current of the short-circuit to earth, without damage. The selective isolation of the generator affected by the short-circuit to earth is then dealt with by the differential protective gear.

A fundamental condition to be complied with in order to ensure an effective selective effect of the differential relay is that the current transformers used should have exactly the same transformation ratio and that this should be the case for all primary currents. If we use two current transformers with different curves of error for a differential protection equipment, there flows through the relay, even when the primary currents are the same, a difference in current which increases with the primary current. If this difference in current exceeds the degree of sensitiveness of the differential relay, the latter comes into

play although there is no fault in the protected part of the installation, this large difference in current being only due to an abnormally high current resulting from an external short-circuit. As soon as the differential protection equipment comes into play for such external short-circuits, this means that its selective effect has been impaired. It is, however, possible in the case of differential protection of generators to reduce the differences in the transformation ratio of current transformers to such an extent that there is no longer any detrimental effect to be feared, when they work together. It is only necessary to use transformers of similar design which are loaded to the same extent on the secondary side, preferably with the differential relay alone. In new power stations with generators having a large short-circuit impedance, in series with transformers with a high short-circuit pressure, the current passing through the service units in the event of an external short-circuit does not exceed 10 to 15 times normal current, so that the disparities in current transformers due to manufacture, which still come into question, can even then be quite well compensated.

The Oerlikon Company build a very sensitive differential relay in the substantial form of a magnet relay, either of flush mounting or projecting pattern (Fig. 8). The power consumption of this relay is 3 VA.

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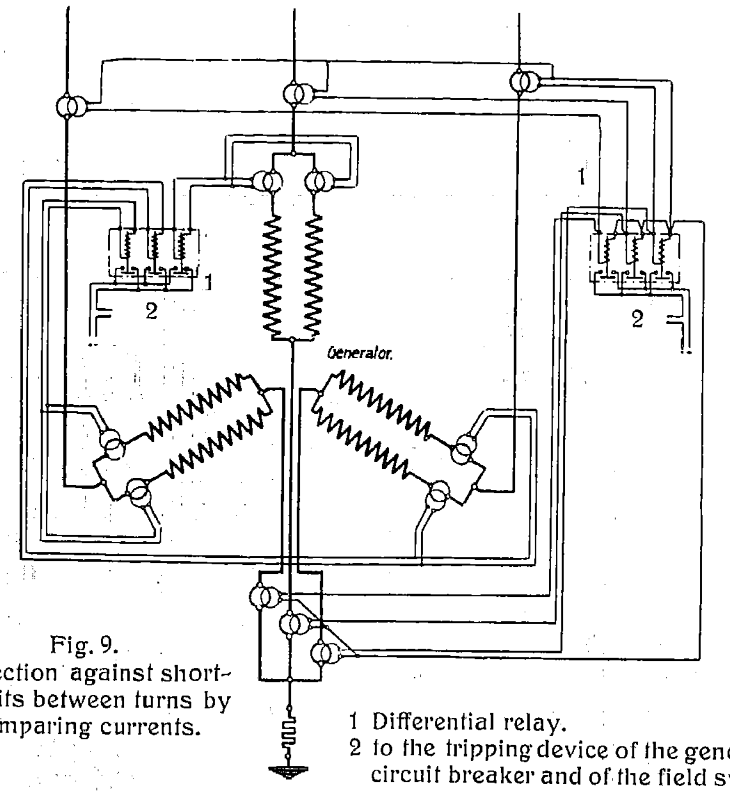


Fig. 9.
Protection against short-circuits between turns by comparing currents.

1 Differential relay.
2 to the tripping device of the generator circuit breaker and of the field switch.

c) Protection against short-circuits between turns.

In order to be able to get some idea of the effect of a short-circuit between turns, we can regard the short-circuited turn as the short-circuited secondary winding of a transformer limb. As the number of turns which are sound is always large, as compared with the number of short-circuited turns, the short-circuit current flowing through the defective turns is very high for this transmission ratio when full pressure is applied and considerably higher than the current supplied by the machine in the case of an external short-circuit. This explains, in fact, the heavy damage which is always observed in the case of short-circuits between turns. It is clear that the damage round the point where the short-circuit takes place soon assumes such dimensions that the insulation against the iron frame also breaks down. In view of this, a short-circuit between turns is, as a rule, accompanied by a short-circuit to earth. Differential protection of a generator with earthed neutral point can thus be regarded, in a certain measure, as a protection against short-circuits between turns.

In the case of machines with bar winding, where the bars are protected by micanite channels and even in machines where there are two bars per slot, the insulation from bar to bar, that is to say, the insulation between turns is twice as great as the insulation to earth, so that short-circuits between turns are less probable than short-circuits to earth. These conditions have to be taken into account when considering whether protection against short-circuits between turns is necessary for a given machine or not.

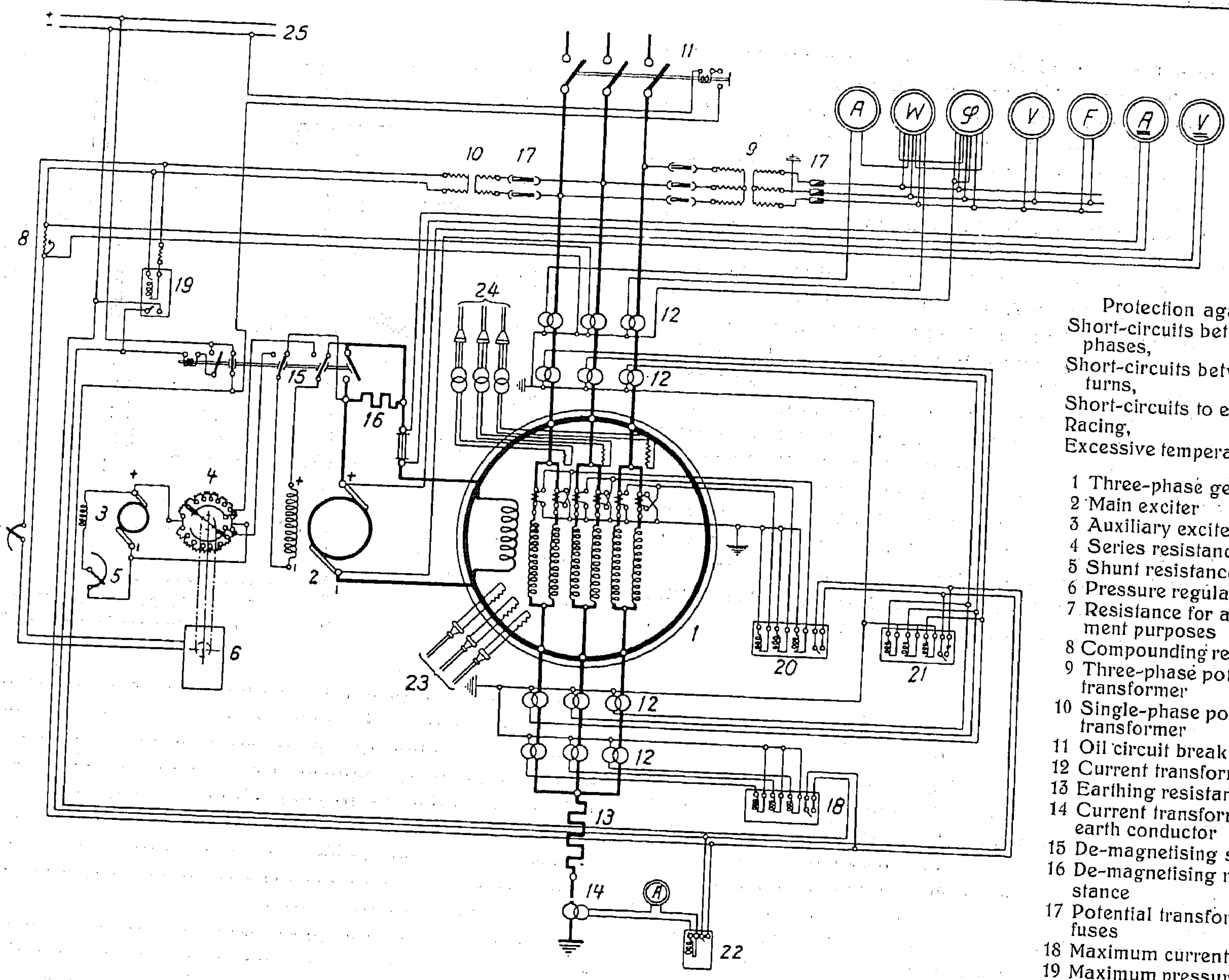
If, however, it is desired to protect effectively the generator against short-circuits between turns, and to cause the rapid switching off of the machine before the damage can assume large proportions, a special protective arrangement must be adopted. Numerous tests have been carried out, in all directions, with a view to finding a suitable solution of this problem. It is also possible to ascertain the displacement of the neutral point of the pressure of the generator in question, that occurs in the event of short-circuits between turns, through comparison with the neutral point pressure of a star connected transformer inserted in the same system. As long as the neutral point of the generator in question is not connected to earth and the measuring devices are so designed as to be unaffected by the higher harmonics which can also flow through the plant in the case of a disturbance in service, this mode of protection is practicable. As soon, however, as the neutral point is earthed, as in the case of most large generators, another solution has to be sought.

There is a method often used in America which is, however, only possible in the case of machines with at least two parallel circuits; it consists in the differential comparison of the current in these two different parts of winding of the same phase (Fig. 9). By combining this internal differential arrangement with the differential arrangement covering the whole generator, it is possible to obtain a protective arrangement which acts in the case of all faults within the machine.

These devices come into play in the case of any dissymmetry in the parallel circuits. As, however, faults such as may occur in the generator do not affect in most cases, to the same extent, the different circuits, an arrangement on these lines affords a sure mode of protection which is also effective against short-circuits in general, short-circuits between winding and frame, and even against short-circuits to earth.

The decision as to whether protection against short-circuits between turns is to be provided or not is to be arrived at before designing the generator, as the choice of the protection is governed by the internal arrangement of conductors of generator. For both modes of protection, the Oerlikon Company use the differential relays referred to under III b. Fig. 10 gives a complete diagram of connections for the protection of a three-phase generator, by means of differential relay, against short-circuits between phases and short-circuits to earth, and by means of differential pressure relay, against short-circuits between turns.

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Protection against:
Short-circuits between phases,
Short-circuits between turns,
Short-circuits to earth,
Racing,
Excessive temperature rise.

1 Three-phase generator
2 Main exciter
3 Auxiliary exciter
4 Series resistance
5 Shunt resistance
6 Pressure regulator
7 Resistance for adjustment purposes
8 Compounding resistance
9 Three-phase potential transformer
10 Single-phase potential transformer
11 Oil circuit breaker
12 Current transformer
13 Earthing resistance
14 Current transformer in earth conductor
15 De-magnetising switch
16 De-magnetising resistance
17 Potential transformer fuses
18 Maximum current relay
19 Maximum pressure relay with series resistance
20 Protection against short-circuits between turns
21 Differential relay
22 Earth current relay
23 Distance measurement of stator core temperature
24 Measurement of stator copper temperature
25 Auxiliary current

Fig. 10.
Diagram of connections of the complete protective equipment of a three-phase generator.

d) Protection against rise in pressure due to increase in speed.

Should it happen that, when the generator is entirely relieved of its load, that is to say, when it is taken off the system, the governor of the driving machine, at the same time, fails to act, the set races, that is to say, its speed increases to the value where the sum of the light load losses is equal to the power supplied. In the case of the water turbine designs resorted to up to now, this run-away speed was about 1.8 to twice normal speed. It has become the usual practice to dimension the generators, mechanically, in such a way that they can withstand, without damage, the centrifugal forces that come into play in the event of the plant racing. All reputable makers of generators therefore subject every generator for water turbine drive to an over-speed test at the run-away speed indicated by the turbine makers. In the case of other driving machines, such as steam turbines, for instance, it is no longer possible to produce a design enabling the plant to withstand the forces to which it is subjected in the event of the machine racing. Everything depends, therefore, on the reliability in operation of the emergency governor which cuts off entirely the steam or the fuel supply, when a given speed (for instance, 10 % above normal speed) is exceeded. In the case of modern high speed water turbines of the propeller or Kaplan type, the run-away speed amounts often to three times normal speed. The constructional difficulties in evolving a design capable of withstanding run-away conditions are, therefore, such that a solution with emergency governor presents undoubtedly economical advantages. As, however, the closing time of the turbine cannot be reduced below a certain minimum value, owing to the dangerous water hammer effect caused by the column of water behind it, and in view of the fact that it is just these high speed turbines that utilise large quantities of water, so that an arrangement for simultaneous by-passing of turbine is uneconomical, generators for water drive will, for a long time, still have to be built sufficiently strong, mechanically, to withstand the run-away speed; consequently, the generators are not liable to suffer any damage, mechanically, in the case of the plant racing. The question is, however, a different one when we consider the electrical side. In modern installations, it is the practice to adopt throughout, for generators, individual excitation, the exciter being built on to the generator or at least driven off the same shaft. As, however, the built-on exciter is a self-excited D. C. machine, its pressure increases with the square of the speed, if we leave entirely

out of account the magnetic saturation. The generator is thus excited at this increased D. C. pressure, in the event of the plant racing, and develops an A. C. pressure which would be proportional to the third power of the speed, if we neglect, here too, the saturation. In practice, however, the pressure under run-away conditions increases hardly in the same proportion as the square of the speed, this being dependent upon the design of machine; it would, nevertheless, reach a value which may not only endanger the installation but definitely damage it.

It is, therefore, advisable in the case of high tension generators driven by water turbines to provide maximum pressure protection. For this purpose, use has been made of centrifugal release devices. These devices, however, apart from the sluggishness which often characterises them only come into play according to the linear increase of speed. As, on the other hand, the pressure increases, as pointed out above, with a certain power of the speed, a maximum pressure relay connected to the terminals of the generator, through a potential transformer provides a far more sensitive protection. When the pressure limit for which the relay is set is reached, the latter causes the demagnetisation of the generator. The relay is tuned to the frequency increasing with the speed, by means of series resistances.

Rises in pressure can also occur at the generator terminals in the event of a two-pole short-circuit in the system or after the interruption of a triple-pole short-circuit. These rises in pressure can, however, be effectively dealt with, by fitting an overload limiting device; they are, on the other hand, less dangerous than rises in pressure in the event of racing, owing to their smaller amplitude and shorter duration.

The Oerlikon Company use as maximum pressure relay the same relay system as for differential protection.

e) Overload protection.

In the event of an external short-circuit, the generators working on the short-circuit supply momentarily a very high current which may amount to 10 to 20 times normal current. This current drops, however, very rapidly to the value of the permanent short-circuit current which still amounts to about twice or three times normal current. The generators must be built in such a way that they are capable of withstanding the mechanical and thermal effects of the momentary short-circuit current. The operation of a machine on a short-circuit, with the permanent short-circuit current, for any length of time, may, however, damage the windings, owing to the production of heat. It has, therefore, become the usual practice to reduce, in the event of an external short-circuit, the excitation of the generator working on it by means of an overload limiting device. Through the operation of this overload limiting device, the excitation of the generator is reduced in such a way that the permanent short-circuit current no longer exceeds about 1½ times normal current. In view of this, the danger of excessive heating of the winding, as a result of the short-circuit current, is reduced to such an extent that the time adjustment of the generator circuit breakers can be considerably increased. This longer time setting of the generator circuit breakers facilitates greatly the application of fault selection in the system by permitting of the adoption of time intervals. As the current of all the machines is reduced by a reduction of the excitation, the oil circuit breakers of the sections which are directly affected by the short-circuit are alone released.

In the case of the pressure limiting devices built by t Oerlikon Company, which are based on the vibrating pri ciple, provision is made for a further coil for the overlo protection, arranged according to a special method. If tl drop in pressure is accompanied by the occurrence of a hea current, as is the case with a short-circuit, this current cc prevents the operation of the pressure coil of the vibratir system, and the resistance in the excitation circuit is kept fro being short-circuited, until the overload current has disa peared once more. In this way, the excitation of the shor circuited generator is reduced to such an extent that the cu rent supplied by the machine does not exceed the permissib limits. Once the short-circuit has been cleared, the overloa protection coil ceases to attract its armature and the pressur regulator builds up again the pressure of the generator in th ordinary way.

As regards the selective isolation of short-circuits in ex ternal parts of the system, this must be attended to by th protective devices chosen for the purpose. If, however, owin to a concourse of unfortunate circumstances, several circu breakers in front of the generators should fail to trip, th latter may suffer damage owing to the excessive current, i these conditions last any length of time. In order to preven this, it is necessary to provide also maximum current protec tion as last resort for the generator oil circuit breaker, th setting being here for a long interval of time (10 seconds fo instance). It is very important that these overload relay should be entirely unaffected by the amplitude of the momen tary short-circuit current, and should only cause the releas of the circuit breakers after the interval for which they are se as otherwise the main advantage of overload limitation is lost

The Oerlikon Company recommend, for the maximum current protection of generators, the use of their new maximum current relays with separate current and time magnets, which fulfil this condition. These relays are built either of the flush mounting or the projecting pattern (Fig. 11).

In the case of quite small generator units, maximum current protection can be regarded as sufficient. In order to be able to deal, however, with short-circuits inside the generator itself, it is advisable to open the neutral point and to insert relays or their transformers between the generator terminals and the external neutral point. It is, however, absolutely necessary to connect current transformers for overload limiting devices on the distribution system side of the generator so that they can only operate in the case of external short-circuits. In the case of internal defects, it is the rest of the protective

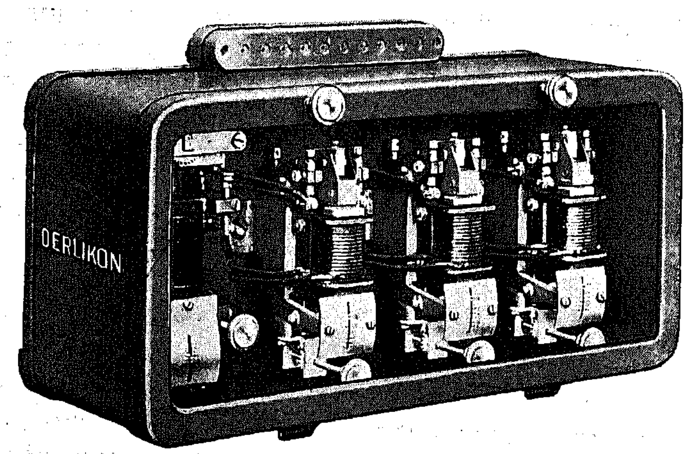


Fig. 11. Triple-pole independently acting maximum current relay.

contact which causes the release of the oil circuit breaker when the field switch is open. In the case of machines working alone, this further results in a certain reduction of the power to be interrupted by the oil circuit breaker when opening. With machines working in parallel, however, the effect of the retarding action of the field switch cannot be overlooked. This matter is to be investigated shortly by means of tests.

IV. Different classes of faults in the case of transformers.

In addition to the faults liable to occur in generators, which are detailed in the corresponding section under 1 to 4, the following internal faults can be encountered in transformers:—

7) Breakdown between the H. T. and the L. T. winding.

8) Burning out of core.

In the case of properly built modern transformers, these two classes of faults hardly occur any more. The first is encountered only in the event of moisture penetrating into the transformer. Moreover, it corresponds to an incomplete short-circuit of the high tension winding to earth and results in a very short time, in an actual short-circuit to earth. The burning out of core is the result of a short-circuit path in the iron core, due to insufficient insulation of the holding bolts, etc. It must, therefore, have the same effect on the transformer as a short-circuit between turns. There is, however, this difference that, while a short-circuit between turns in the winding becomes immediately conductive, owing to the large quantities of copper, the burning out of the core can last a long time, before it becomes noticeable, as a result of the increase in current consumption or of the rise in temperature.

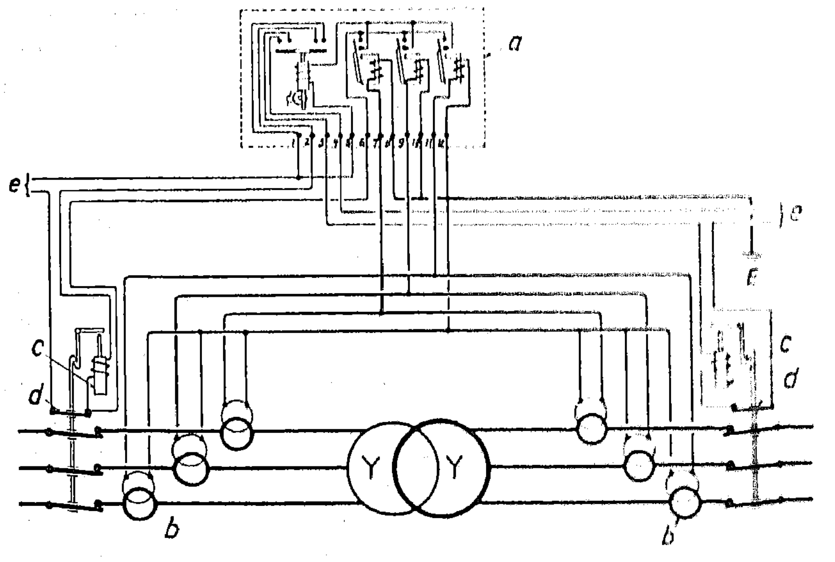
V. Different modes of protection for transformers.

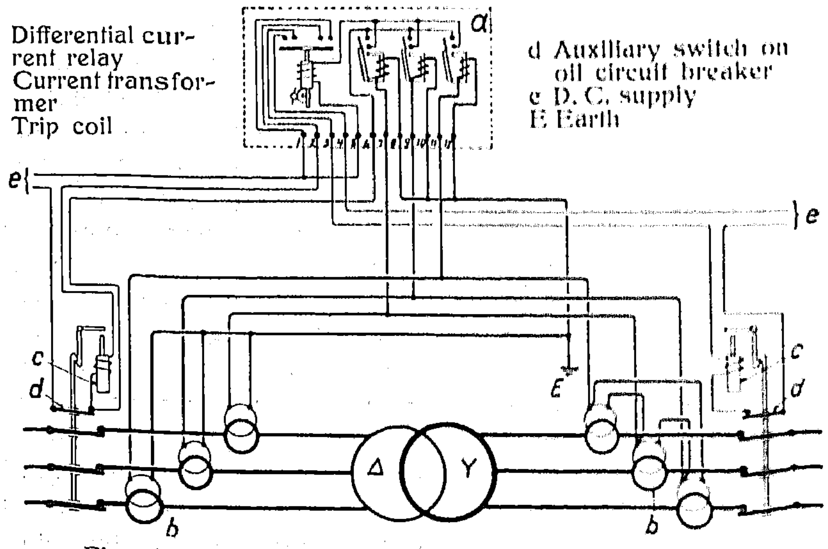
a) Differential protection.

In many quarters, overload protection is still regarded at the present day, quite incorrectly, as sufficient protection for a transformer. The overload relay has, however, to be set for a higher current than normal current and can therefore only deal with faults when the fault current exceeds the normal working current. It is, therefore, necessary for the protection of transformers to use special relays. In order that the transformers should be included in the comprehensive scheme of protection of the system, extending from the generator to the consumer, it is often advisable to provide maximum current relays, in addition to the protection of the transformer. The current and time adjustment of the latter is, however, governed by the requirements of the system. In view of the current rush when starting up, it is advisable to use here maximum current relays of which the time setting is entirely independent of the current, such as utilised for the overload protection of generators.

The only method which is suitable for the protection of transformers is the differential method. The primary and secondary current are then compared in each phase. The application of this principle is, however, linked with certain difficulties which reside in the dissimilarity of the current transformers used which, for reason of their purpose, belong to various pressure types. These difficulties are greatest when the current transformers are of the bar type on one side of the transformer and of the coil type on the other. The Oerlikon Company have studied the conditions from the theoretical point of view and also in their test room; they are in a position, on the basis of the curves obtained for existing current transformers, to provide the necessary compensation for differential protection by introducing auxiliary transformers, in such a way that the protection in question cannot give rise to faulty release even in the event of the most heavy short-circuits, to which the installation may be subjected.

The sensitiveness of all differential relays used with transformers is not merely limited by question of design, but rather by the fact that, when setting the relay the light load current has to be taken into account. In this connection, it must be borne in mind that, when the transformers are somewhat highly saturated, the magnetising current and, consequently, also the light load current rise very rapidly when the pressure is higher than normal. In view of this, it is the practice not to set the differential relays for less than double the value of light load current measured for a pressure 10 % above normal, or for less than 3 to 4 times light load current at normal pressure. The light load current at normal pressure for transformers with capacities such as come into question is of the order of magnitude of about 5 % full-load current. In order to be quite sure that the differential protection operates in the case of the heaviest external short-circuits, various supply companies





a Differential current relay
b Current transformer
c Trip coil
d Auxiliary switch on oil circuit breaker
e D. C. supply
E Earth

Figs. 14 and 15. Differential protection for transformers either star-star connected or delta-star connected.

have arranged to set their differential relays, on principle, in such a way that they come into operation for a difference in current equal to normal current. As a result, the differential protection looses its characteristic of providing fine protection, but gains, on the other hand, in the matter of absolute reliability as regards selective effect.

When arranging for differential protection, it is necessary to take into account the way in which the transformers are connected internally. If the transformers are star-star connected, the currents in the current transformers on the HT and LT side respectively, have a phase displacement in relation to each other of nearly exactly 180°. The individual phases can, therefore, be compared together directly, as shown in the diagram in Fig. 14. The current transformers are then built for a transformation ratio to give the same secondary current 5 or 1 amp, for instance. When the main transformers are delta-star connected, it is no longer possible to compare one phase with another, as the two current vectors to be compared are not directed along one straight line, but form an angle of 30° or 180° + 30°. In order to correct this, it is necessary to adopt delta connection for the three current transformers on the star-connected side of the transformer, and to resort to star connection for the current transformers on the delta-connected side of transformer. The three phases of these two three-phase systems thus formed are connected together, and the three phases of the differential relay, which are also star-connected, are linked up with them as shown in Fig. 15. In this case, the current transformers are no longer to be built for a transformation ratio to give the same secondary current. If, for instance, we take for the delta-connected current transformers 1 amp as secondary current, the star-connected current transformers must have a current $\sqrt{3}$ greater, that is to say, 1.73 amps, in order that it should be possible to compare it with the corresponding current on the delta side.

In view of the current rush when starting transformers on light-load, which current can reach the value of normal current and even considerably exceed it, it is highly advisable to design the differential relay so that it should operate with a slight time lag. If the transformers to be protected are provided with tappings, the course that can be adopted when the difference in ratio is relatively large is to use current transformers with corresponding tappings or to insert auto-transformers permitting of the necessary adjustment, between current transformers and differential relay. Anyhow, it is advisable in the case of differential protection of transformers, not to require too much sensitiveness, in order to guard against faulty releases caused by the accidental cumulation of such inaccuracies as must inevitably be encountered in the equipment.

The differential protection gear comes into play, not only in the case of short-circuits between phases, but also in the case of short-circuits between turns, owing to the heavy increase in current that takes place in the sound winding. At the same time, it provides, for transformers, effective protection against short-circuits to earth, of course, only in cases where the neutral point is earthed (in which connection, the same remarks apply as for generators), or when conductors with a large earth capacity are connected to the winding in question, so that the current of the short-circuit to earth suffices for the operation of the differential relay; it also affords protection against interruption in conductors, as this upsets the balance of currents. Protection is obtained in the case of the burning out of core only when this has the same effect as a short-circuit between turns. When generator and transformer are directly connected together so as to form service units, the idea of providing joint differential protection for the whole unit may seem attractive, as in this way it is possible to save, in the case of a three-phase supply, six current transformers insulated for the generator pressure. This combining of the protection of generator and transformer presents, however, various drawbacks. Differential protection which, owing to its nature, comes under the category of fine protection, can actually be used as such for generators, with a degree of sensitiveness of about 5% of rated current, for instance. If, however, the protective equipment is for generator and transformer, the degree of sensitiveness has to be reduced considerably, as mentioned above. On the other hand, should it be desired, in the event of there being an auxiliary busbar system, to couple the generator with another transformer, on account of a defect in a transformer, complicated connections are necessary on the secondary side, with the result that the reliability of equipment and the supervision facilities are impaired. It is thus highly advisable, in order to simplify the connections and to obtain fine protection for the generator, to protect generator and transformer independently.

For the differential protection of transformers, use is to be made of the same relays as for generators (Fig. 8).

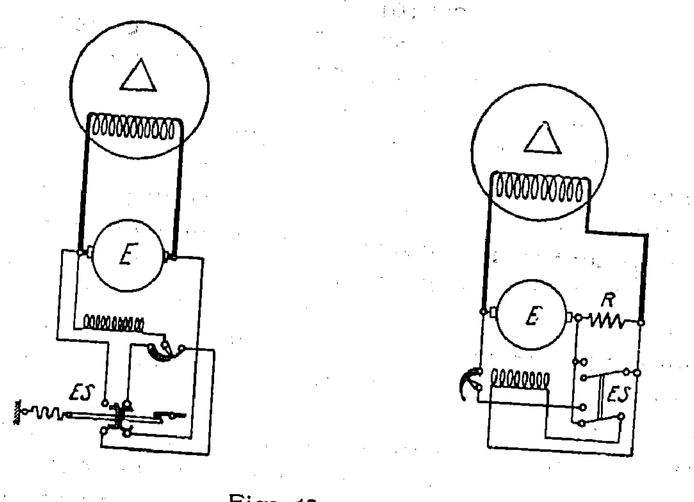
b) Buchholz Protection.

This type of protection is based on a chemical phenomenon, namely, on the decomposition of the insulating medium by the fault current. When such a decomposition takes place, gas bubbles always form. These bubbles rise in the oil and collect in the Buchholz protection apparatus, on their way to the oil expansion vessel, where they are used for operating a signal and for the release of gear. The Buchholz apparatus (Fig. 16) contains two floats b_1 and b_2. The volume of gas that increases gradually at the top of the cylinder, a, forces the oil out of the latter. As a result, the float b_1 moves downwards until it reaches a certain level, where it closes the contact c_1 of the alarm signal. Warning is thus given after a short time, even in the case of small faults such as incipient ageing, creeping currents, etc. If the defect in the transformer is a serious one, the formation of gas is violent and takes place in spurts. The pressure wave thus produced is guided upwards through the oil and meets, on its way to the expansion vessel, in the lower part of the Buchholz apparatus, the second float b_2; the latter acts as a flap and, as it tips over, closes the release contact c_2 which, in turn, causes the tripping of the oil circuit breaker.

It has been fully established by a large number of tests and by the results obtained in practice that the Buchholz protective gear is entirely suited to its purpose and very sensitive; it operates in the case of all faults inside the transformer and also comes into play in the event of excessive load, as soon as the insulation is endangered.

The Oerlikon Company have been granted a licence giving them the right to use the Buchholz apparatus with their transformers in the case of all countries with the exception of Germany, Austria, Hungary, Czecho-Slovakia, Yugo-Slavia, Poland, the United States and Canada. When the characteristics of the transformer in question are known, the Oerlikon Company submit, on application, a complete quotation and are in a position to supply detailed particulars and descriptive matter.

equipment that is to come into play and to demagnetise the generator entirely, and close it down.



Figs. 12 a and b.
Diagrams of connections for the de-magnetisation of generators.
a) De-magnetisation by means of a discharge resistance.
b) De-magnetisation by means of the Oerlikon quick-acting de-magnetisation method.

f) Rapid demagnetisation.

When a generator has an internal defect, whether it be a phase short-circuit, a short-circuit between turns or a short-circuit to earth, it is not sufficient, in order to limit the damage only to release the oil circuit breaker and thus to disconnect the plant from the system. It is, further, necessary to prevent it from working with its own pressure on the fault and from thus destroying itself. It is only possible to guard against such an occurrence by arranging for the rapid demagnetisation of machine. The decrease in excitation through the action of the overload limiting device is not sufficient for this purpose as the excitation is only reduced as long as the current supplied by the machine exceeds a value somewhat above that of the rated current. What is required is an entire demagnetisation, which destroys even the remanent field, as the remanent pressure may be sufficient to maintain an arc. There is, of course, great interest in causing the demagnetisation to take place as rapidly as possible, as the arc has not the time then to cause any great damage to the machine. The arrangement still often used of switching over the field of the exciter from the armature to a resistance (Fig. 12, mode of connection a) results in a slow damping of the excitation current, and the generator still retains at the end its remanent pressure.

This method is thus only suitable for small units in the case of which the equipment has to be kept as simple as possible. With generators having a large capacity, it is a matter of utmost importance to ensure rapid demagnetisation.

The Oerlikon Company have devised a special patented arrangement for the demagnetisation of generators, which acts extremely rapidly (Fig. 12b). In the case of a breakdown, the shunt wound exciter is converted into a shunted series machine by a change-over switch. The magnetic energy of the rotor of the generator is discharged into the shunt resistance and into the field winding of the exciter in parallel with it. The exciter is connected to the resistance in such a way that the current flowing through it changes its direction in relation to the direction before the fault; in view of this, a pressure is produced in the armature of the exciter which is opposed in direction, so that the rotor current and, consequently, the short-circuit current supplied by the generator to the fault, too, are damped very rapidly. This method of demagnetisation has been tested in our test room on various machines and has been compared with other known methods. The oscillographs taken show how rapidly the pressure of the exciter assumes a negative value and how rapidly the current of the rotor and the stator are damped in this way. The Oerlikon Company recommend the use of this method of rapid demagnetisation for all large machines.

Rapid demagnetisation must always be applied when there is an internal defect. In the case of external defects, there is, however, no need at all to demagnetise the machine; this may, on the contrary be detrimental for the rapid re-paralleling of plant. It is, therefore, always necessary, when the circuit breaker is released, to differentiate between the case of an internal fault and that of an external fault.

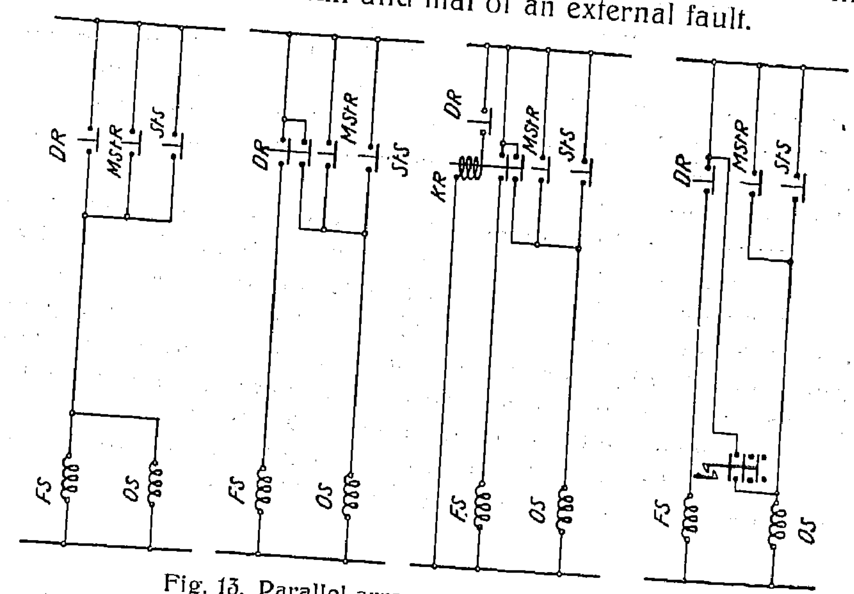


Fig. 13. Parallel arrangement of trip coils.

a Trip coils permanently in parallel — b Release by means of double-pole relay contacts — c Release by means of shutter type relay — d Release by the field switch itself

OS	Trip coil of the oil circuit breaker
FS	Trip coil of the field switch (de-magnetising switch)
DR	Differential relay (i. e. relay for internal faults)
MStR	Maximum current relay (i. e. relay for external faults)
StS	Tripping switch
KR	Shutter type relay

The arrangement with the two trip coils of circuit breaker and field switch in parallel according to the mode of connection in Fig. 13a is, therefore, not to be recommended. In the case of the mode of connection b), the oil circuit breaker alone is released, when the maximum current relay MStR comes into play, while when the differential relay comes into operation, both the oil circuit breaker and the field switch trip. All relays which indicate internal defects must, however, be provided with double-pole release contacts. This results not only in a complication of relay, but also has the still more undesirable effect of rendering the relay less sensitive owing to the larger torque required. For this reason, the Oerlikon Company do not use the mode of connection b). Instead of using double-pole contacts on the protective relay, it is, of course, possible to resort to two-pole auxiliary relays, preferably of the shutter type, such as shown in Fig. 13c). We have adopted this solution for automatic installations; it presents the notable advantage of giving the location of the fault. The field switch itself can also take the place of an auxiliary relay as long as it is provided with an auxiliary

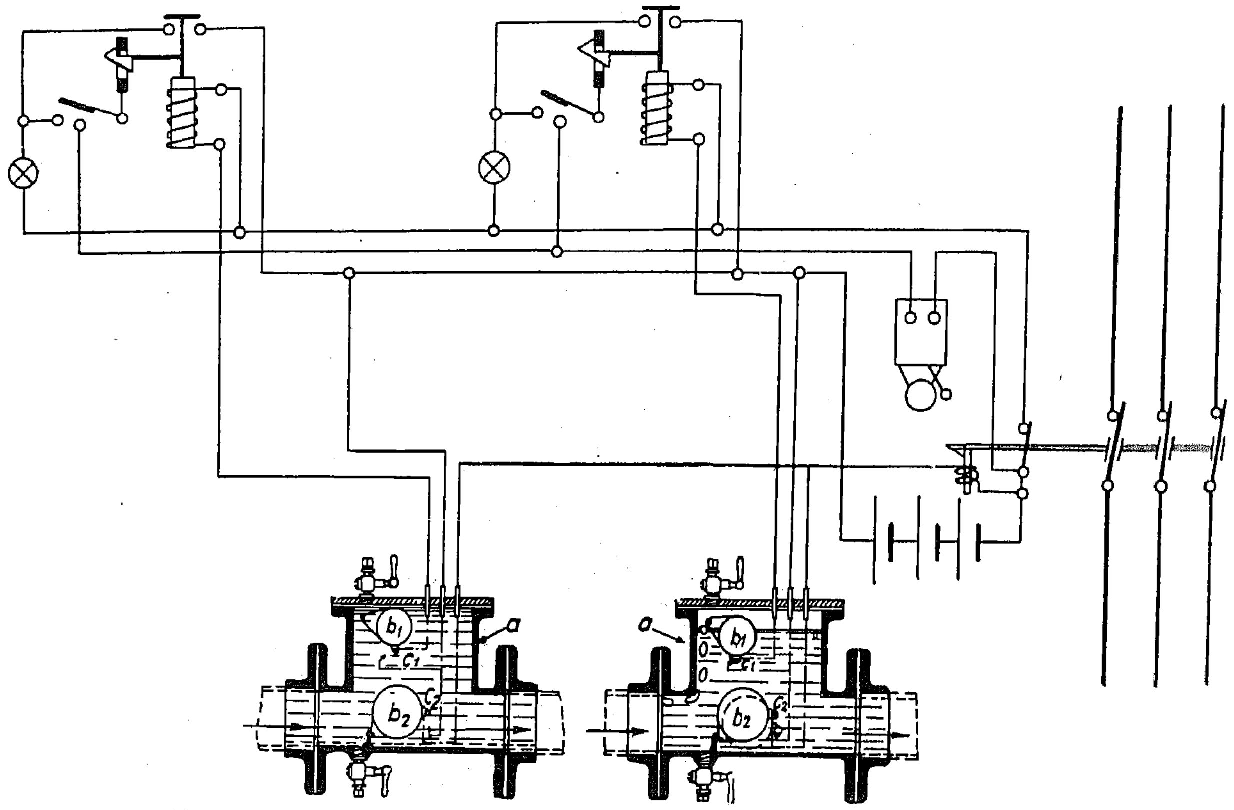


Fig. 16. Diagrammatical representation of the Buchholz mode of protection.
a = Cylinder — b_1, b_2 = Floats
c_1 = Contact of alarm signal — c_2 = Release contact

VI. The supervision of the conditions of operation.

In order to prevent the occurrence of faults, it has become the practice, in all power stations, to keep a check on the variations of certain characteristic quantities. These are, in particular, the temperature in the iron, in the copper, in the air ducts, in the oil, in the cooling-water, etc., and also the rate of circulation, the rate of flow or the pressure of the cooling air, of the cooling water or of the cooling oil. The Oerlikon Company build the necessary devices to check all these quantities and have recently devised a special shutter type relay for the purpose. This relay brings into operation two alarm signals — an acoustic and an optical one. The former can be stopped at will, while the latter continues to function and give warning, until the disturbance has been attended to. These relays are described in a special publication which also contains diagrams for open and closed circuit working.

The Oerlikon Company also submit quotations for distance thermometer equipments for direct current or alternating current, for measuring the temperature at points which are under pressure. The necessary measuring elements for these equipments can be embodied in the generators and transformers, if desired or as arranged, and as conditions permit.

These equipments and relays do not cause the closing down of the unit in question; they merely serve to draw the attention of the staff to the dangerous conditions in the plant, by giving a warning signal. This gear does not, therefore, act in a strictly selective manner; it serves rather to give to the staff the opportunity of putting the matter in order, before a fault actually occurs, and the closing down of plant becomes absolutely necessary.

VII. Auxiliary current supply.

An absolutely necessary condition for the complete selective protection of a power station is that there should further be an independent source of current available, at all times, preferably in the form of a battery of accumulators, for the supply of current for all the release operations that have to take place. There are, it is true, methods of connection where the tripping of gear is done by means of the current or the pressure of the circuit protected. These solutions cannot, however, be regarded as fully effective, as the protective gear either fails to act when the pressure itself disappears in the neighbourhood of the fault or gives only very coarse protection, as the fault current has to reach a definite value before the release can take place. These solutions are, therefore, only resorted to in the case of small power stations.

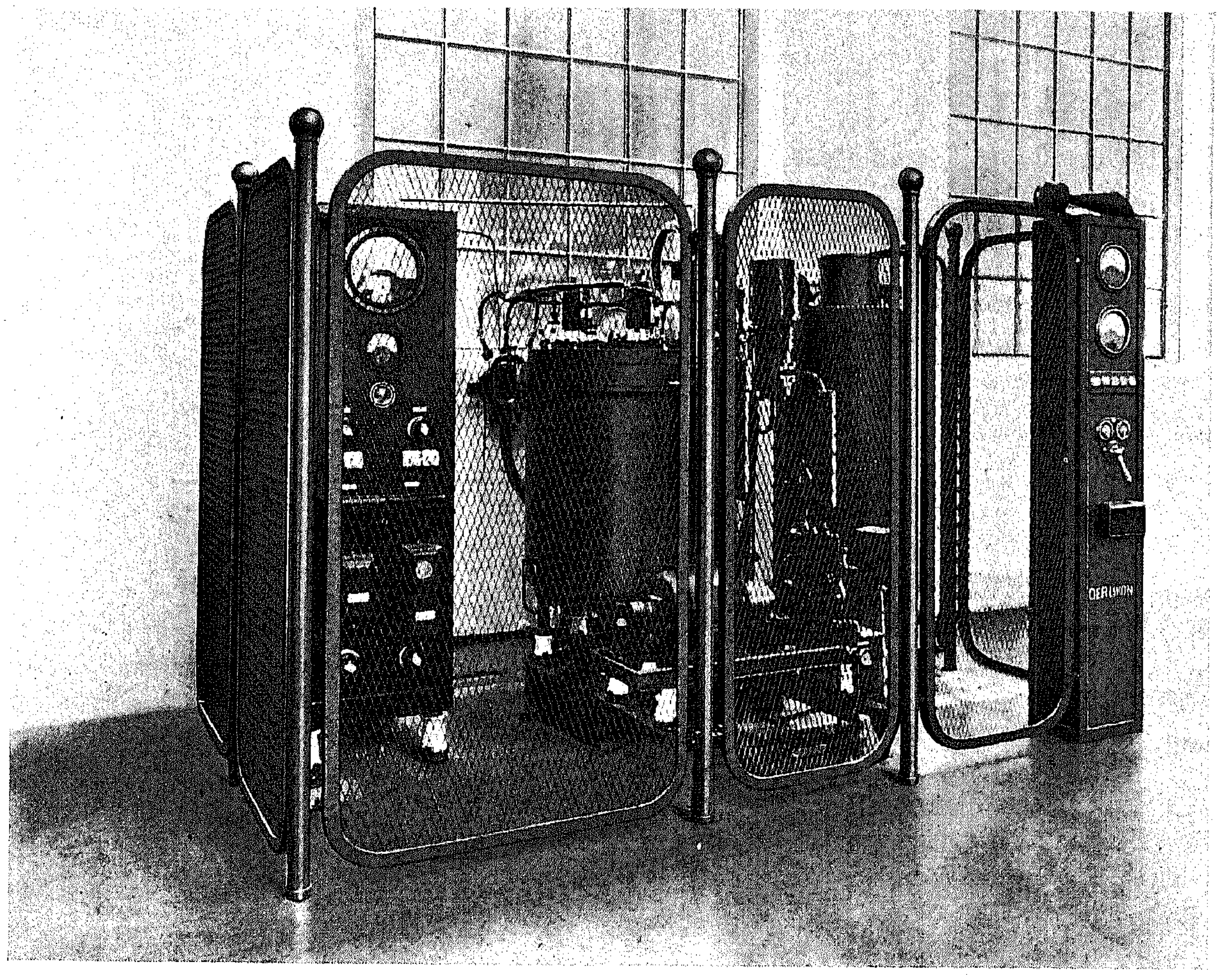
As defects in generators and transformers are infrequent as compared with disturbances on overhead transmission lines, complete selective protection can, in fact, be dispensed with for the sake of simplicity when the units are small. If, however, the units are large in relation to the total capacity of the power station in question, the superintendent has such a heavy responsibility to bear that he will do all he can to ensure that his machines are effectively protected.

ATELIERS DE CONSTRUCTION OERLIKON, OERLIKON

BULLETIN OERLIKON

No. 107 — May 1930

Contents: New mercury rectifier equipments.
The four-axle tramcars of the Zurich Municipal Tramways.
Notes and News Items: New orders for locomotives for the Swiss Federal Railways.



800 KW mercury rectifier equipment of the Bernese Oberland Railways, at Zweiluetschinen.

New Mercury Rectifier Equipments.

In the middle of October 1929, the 800 KW mercury rectifier plant supplied to the Bernese Oberland Railways for the Zweiluetschinen power station was put into service. The whole equipment is working entirely satisfactorily. A specially notable feature is the small D.C. pressure drop between light load and full-load, which only amounts to 3.8%. In view of this, it was possible to comply without difficulty with the condition laid down by the Railway Company that the new plant was to work in parallel with the existing rectifier set, which latter is equipped with negative booster reactance. This result has been achieved by using a transformer with star-connected winding on the primary side and six-phase zig-zag connected winding on the secondary side, special attention being paid to the leakage conditions in the windings. In this way, it has been possible to dispense with negative booster reactance, with its attendant drawbacks. The full-load pressure is 1550 volts.

In November 1929, the semi-automatic 500 KW installation of the United Bern-Worb Railways was put into operation. The plant in question is characterised by its simple construction and the little room it requires, these being special features of the Oerlikon design. The whole equipment including the high tension gear, the mercury rectifier, the cooler and the line circuit breakers, is accommodated on a floor surface of about 130 sq. ft. in an extension of the existing power station provided for the purpose, without the access to plant and the supervision facilities being impaired in any way.

At the present time, two fully automatic installations for tramway operation are being erected, one at the power station of the Lighting and Water Supply Authorities of the town of Zug and the other at the Municipal Electricity Works of the town of Uster.

A detailed description of the new designs of rectifiers used in the installations in question, where they have proved entirely satisfactory, will be given in a subsequent issue.

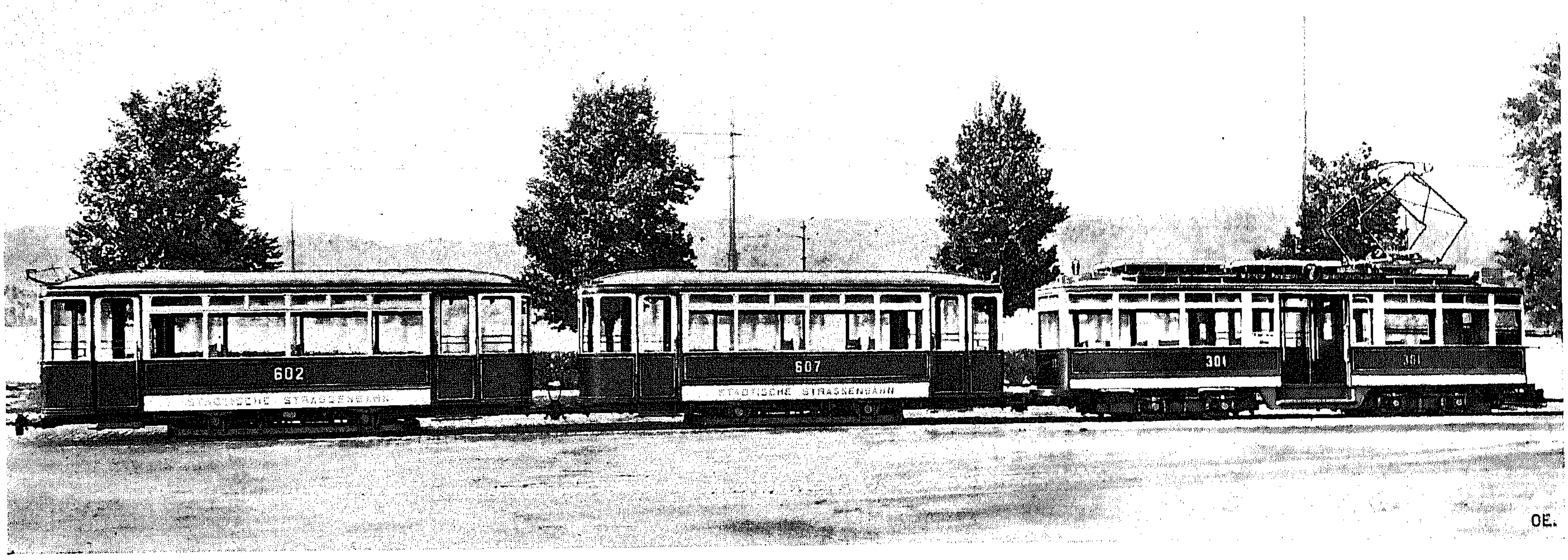


Fig. 1. Three-car train. Normal passenger accommodation for 120 persons.

The Four-axle Tramcars of the Zurich Municipal Tramways.

At the beginning of August 1929, trials were carried out on the line No. 5 of the Zurich Municipal Tramways with a first four-axle tramcar, belonging to a series of fourteen cars in the course of construction. This car was subsequently put into operation on route No. 7 and, by the end of 1929, eight of these cars were in service, the rolling stock in question being primarily intended for lines Nos. 7 and 10, two of the lines with the heaviest traffic and with gradients up to 60‰.

The idea to use four-axle tramcars on the Zurich Municipal Tramways was not a new one. The obstacles that stood in the way of this design of tramcar were, on the one hand, the lay-out of the track and curves in one of the principal squares in Zurich – the Paradeplatz – while, on the other hand, a contention advanced against the introduction of four-axle tramcars was that they were uneconomical, owing to the bad average utilisation of the passenger accommodation.

As a result of the re-laying of the track in the Paradeplatz, the objection against four-axle tramcars disappeared. At the same time, owing to the extension of the outer quarters of the town, the traffic on certain main lines had increased to such an extent that it was possible to reckon with a good utilisation of the passenger accommodation.

During the rush hours, the volume of traffic attained was such that it became necessary to consider the introduction of three-car trains even on the steep gradients of the lines Nos. 7 and 10. In order to be in a better position to deal with this traffic, the Tramway Commission decided to acquire, provisionally, fourteen four-axle tramcars. With a view to testing out the design of the tramcars, two such cars were ordered, in the first place, and put into service, after which a contract was immediately placed for 12 further cars.

The mechanical part was designed and built by the Swiss Railway Carriage Works of Schlieren-Zurich. The front and back portion of the car had to be narrowed, owing to the existing curves, in order to leave the prescribed clearance, when crossing on curves.

With a prescribed width of car of 2.2 metres (7′ 2″) reduced, at either end of car, to a minimum value of 1.6 metres (5′ 3″), the length of the car body arrived at was 10,940 mm

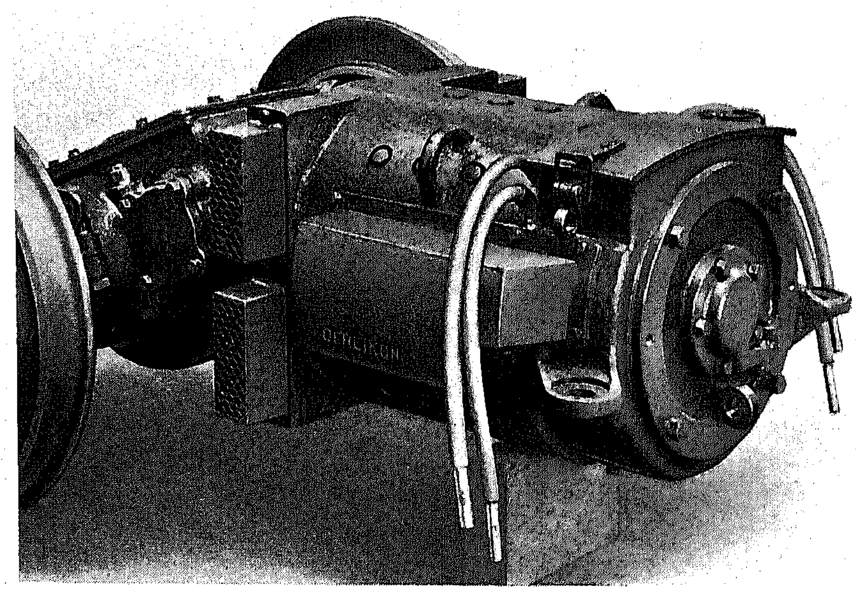


Fig. 2. High-speed traction motor, type E 23 b, with double reduction gear in closed gear box.

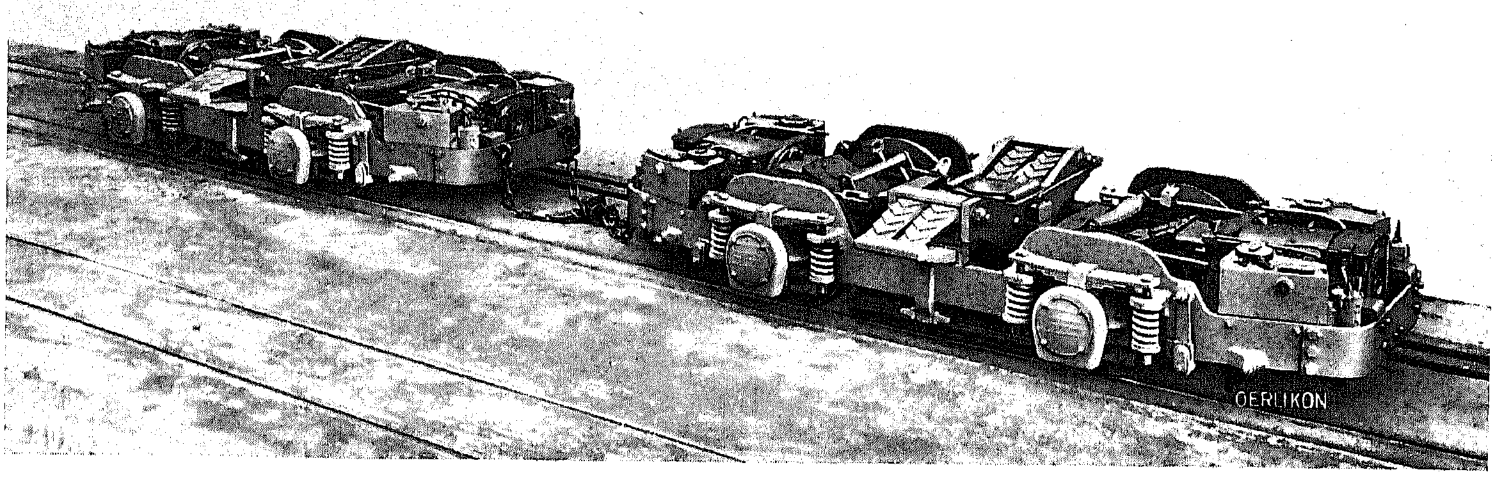


Fig. 3. Bogies of tramcar complete with motors.

(35′ 10″). A further condition imposed was that two loaded trailers, representing a weight of 80 tons, had to be hauled at a speed of 15.5 m.p.h. on gradients of 1 in 13.3. This gave a dead weight of 26 tons for the tramcar and a motor output of 320 HP, which means that this relatively short four-axle car had to be of very substantial construction. In view of the fact that, at most terminal stations, the track of the Zurich Tramways is laid out in the form of a loop, this suggested an arrangement of tramcar with driver's cab closed off from the public, at one end, and with central entrance with double sliding doors, on one side; such an arrangement gave the conductor a better sight of the persons entering and leaving the tramcar.

It was further possible to keep the whole floor of the car in one plane, as in the case of the new two-axle tramcars, by adopting the same diameter of wheel of 610 mm (2′). On the other hand, the fact that the standing place for passengers in the central vestibule was situated in the part of the car where running was smoothest was also generally welcomed.

The iron supporting base of the car body is built in the shape of a trough, the continuity of the latter being interrupted only on one side in the middle, by a piece of cast steel of same strength which is designed as a step.

The frame of the car body is of oak, the partitions of ash and the seats and panels of elm. All the large side-windows in the parts with seating accommodation and the window for the driver are movable and balanced. All the small upper windows are built as movable ventilating windows.

The bogies (Figs. 3 and 4) are of very substantial construction and have a wheel base of 1.55 metres (5′ 1″). The frame of the bogies is sprung in relation to the axle boxes, through laminated and helical springs; on the other hand, it embodies an equalising bar which carries the car body through the intermediary of elliptical springs. There is thus a three-fold spring suspension between the body and the rails. The two first trial cars have roller bearings, the subsequent cars „Isothermos“ axle boxes.

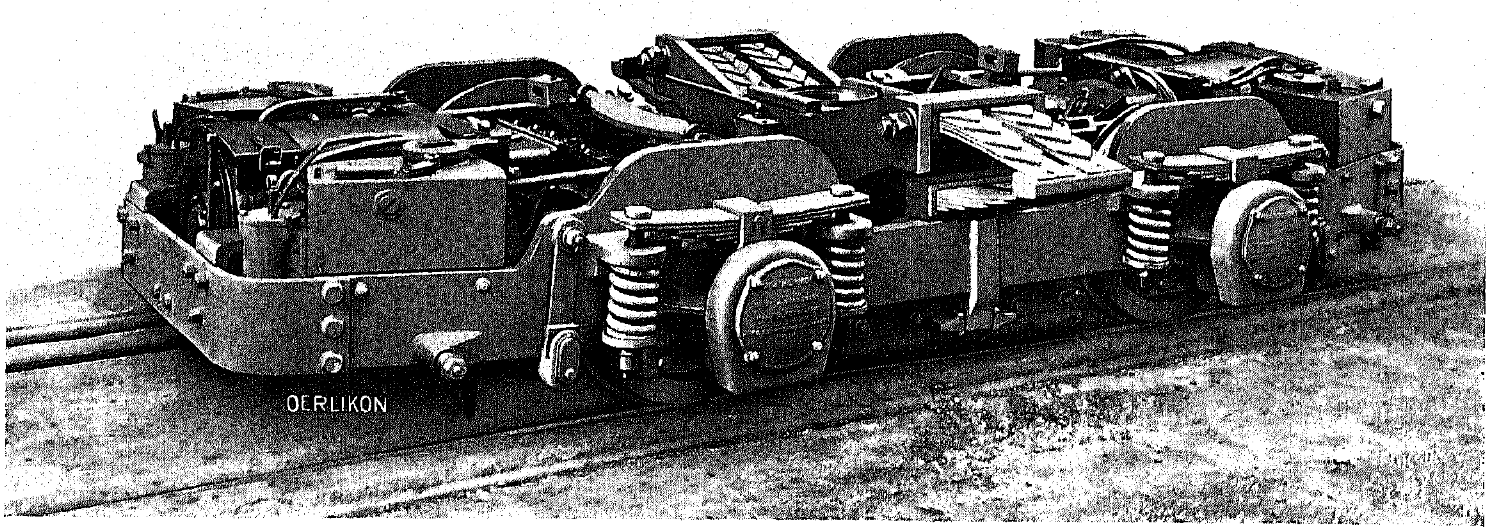


Fig. 4. Bogie of tramcar complete with motors.

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Two types of brakes have been tested up to now on the cars supplied, namely, the inner type brake with 16 brake blocks and the outer type brake with 8 brake blocks.

The inner type brake operates through the intermediary of the brake rigging brake blocks with Hart-Checco lining; these brake blocks press against the inner side of specially shaped wheel tyres. With this type of brake, the wear is minimum. The braking effect is good, but it is not possible to form a definite opinion in this connection until the brakes have been in service for some time.

The design of the outer type brake differs from standard design in this respect, that the cross-members connecting the brake blocks are dispensed with and the guiding of each individual block is ensured by the strong side frames of the bogie. Provision is made, at the four corners of the bogie, for

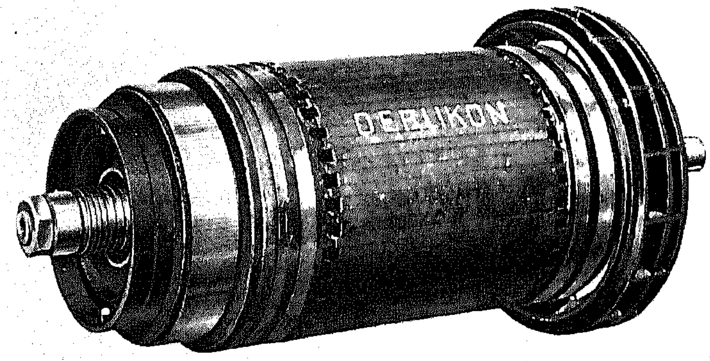


Fig. 5. Armature of motor, type E 23 b.

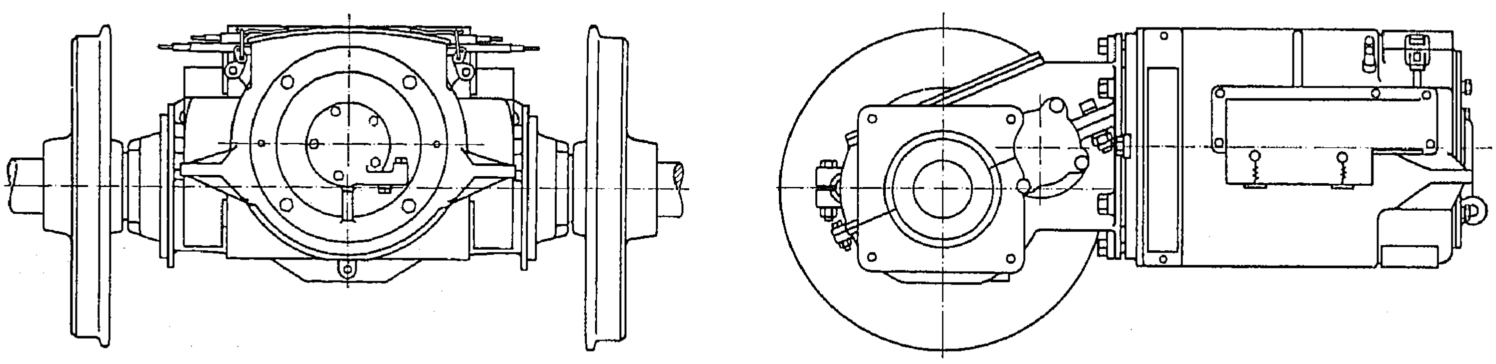
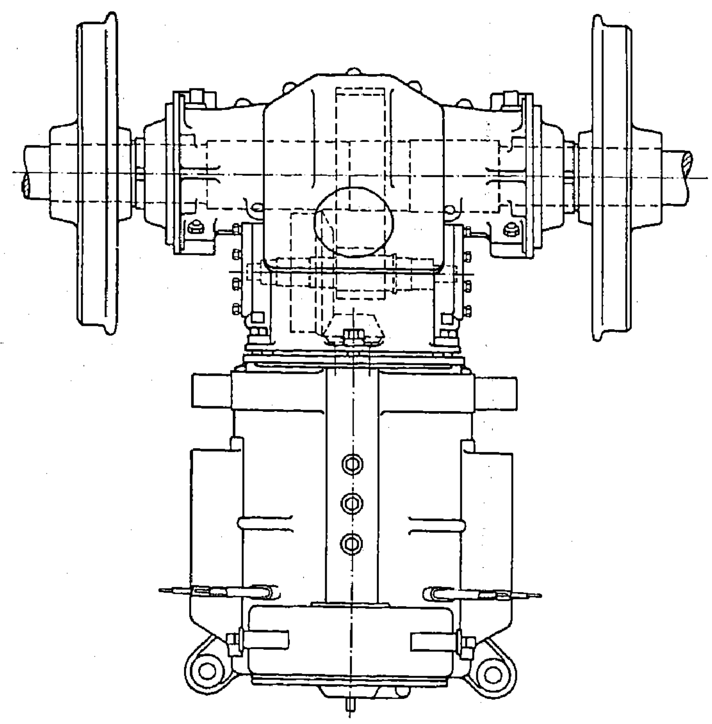
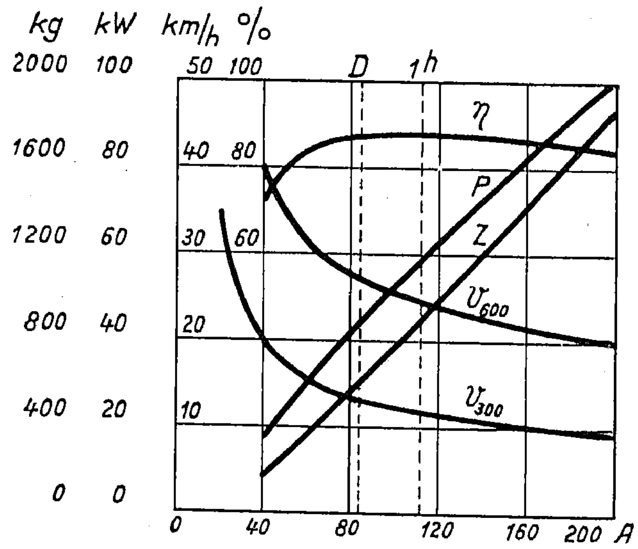


Fig. 6. Motor, type E 23 b, scale 1:20.





Motor pressure 600 volts.

Diameter of driving wheels 610 mm (2').

Gear ratio 1 : 8.578.

P = Motor output at wheel rim, in KW.

Z = Tractive effort at wheel rim, in kgs.

η = Overall efficiency (motor and gears), in %, at 75° C.

v = Speed in km.p.h.

Fig. 7. Characteristics of the motor, type E 23 b.

sand boxes with double valves; the latter can be actuated from the driver's cab by means of remote controlled electro-magnets, in the case of either direction of travel, that is to say, always in front of the wheels.

The motors, in view of their relatively large dimension in the longitudinal direction, are arranged externally in relation to the centre of the bogie and are spring borne.

The coupling of coaches is automatic. Apart from providing the mechanical coupling, it serves, at the same time for connecting up the circuit of the continuous electric brake with brake solenoids and of the electro-magnetic rail brake of the trailer coaches. The circuits of the visual signalling equipment used by the Zurich Tramways and of the emergency signalling

Performance data under normal conditions:

	D = Continuous rating	Ih = 1-hour rating
Motor current	84	111 amps.
Output at wheel rim	44 (60)	59 (80) KW (HP)
Tractive effort at wheel rim	1320	1960 lbs.
Speed	16.7	15 mph.

equipment are connected, from car to car, by means of a cable, so that it is possible to give the warning signal to the driver to stop at once, either from the tramcar or from any trailer.

The lighting and heating circuits are connected together on the roof by means of contact rod and fork, as in the case of all the rolling stock of the Zurich Tramways.

The cars have a length over buffers of 11.54 metres (37′ 10″) a width of 2.2 metres (7′ 2″) and a distance between bogies of 1.55 metres (5′ 1″); the dead weight is 25.2 tons. In the two portions of the car where the seats are arranged, there is accommodation for 25 persons seated, and 4 standing, and, in the central vestibule, for 28 persons standing, that is to say, the car can carry 57 persons in all. This number can, of course, be exceeded considerably during rush hours.

The motor equipment, which was built entirely by the Oerlikon Company, comprises 4 self-ventilated traction motors, type E 23 b, with double reduction gear, such as used with the best results on the new rolling stock of the Zurich-Oerlikon-Seebach Tramways and on the two-axle tramcars, Nos. 9—20, of the Zurich Tramways. The one-hour rating prescribed for the motors, type E 23 b, of the four-axle tramcars was 80 HP. at 600 volts. This means that these four-axle tramcars of the Zurich Tramways, which develop 4×80 HP. at wheel rim are the tramcars with the highest motor rating in use on Swiss tram lines. It may be mentioned here that a study was also made of an alternative with motors fitted with single reduction gear and arranged with motor shaft parallel to the driving axle, the motor equipment being then mounted within the given wheel base; it was found that such a solution was quite possible. Nevertheless, it was decided to adopt motors of the type E 23 with double reduction gear, in order to have as far as possible motors of a uniform type in service. Experience has since shown that the arrangement with motors outside the wheel base did not give rise to any detrimental effect when running on curves. The design of the motors can be seen from Figs. 2 and 6, while Fig. 5 is a view of the armature of the motor. The characteristics of the motor are plotted in Fig. 7.

The heating tests carried out on these self-cooled motors, working at their one-hour rating, gave very good results. In fact, the temperatures of the armature, the field and the interpoles were, in certain cases, 50% below the permissible values. The noise, due to the gears and the fan when running, was not at all troublesome, even with a speed of armature of about 2000 RPM. All bearings are built as roller bearings.

At the request of the management of the Zurich Tramways, the inlet and outlet openings for the ventilation of these self-cooled motors were arranged in such a way that they could be closed, so as to be able to run the motors without ventilation during the cold winter months. The ventilation flaps can be closed or opened, by means of a simple handle, from the inspection pit.

The controller (Fig. 8) is built for direct control. In spite

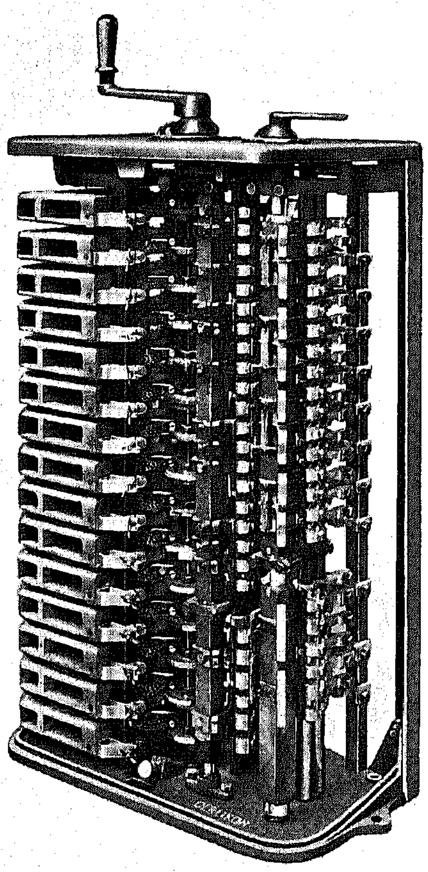


Fig. 8. Controller for 4 motors with cam control, casing removed.

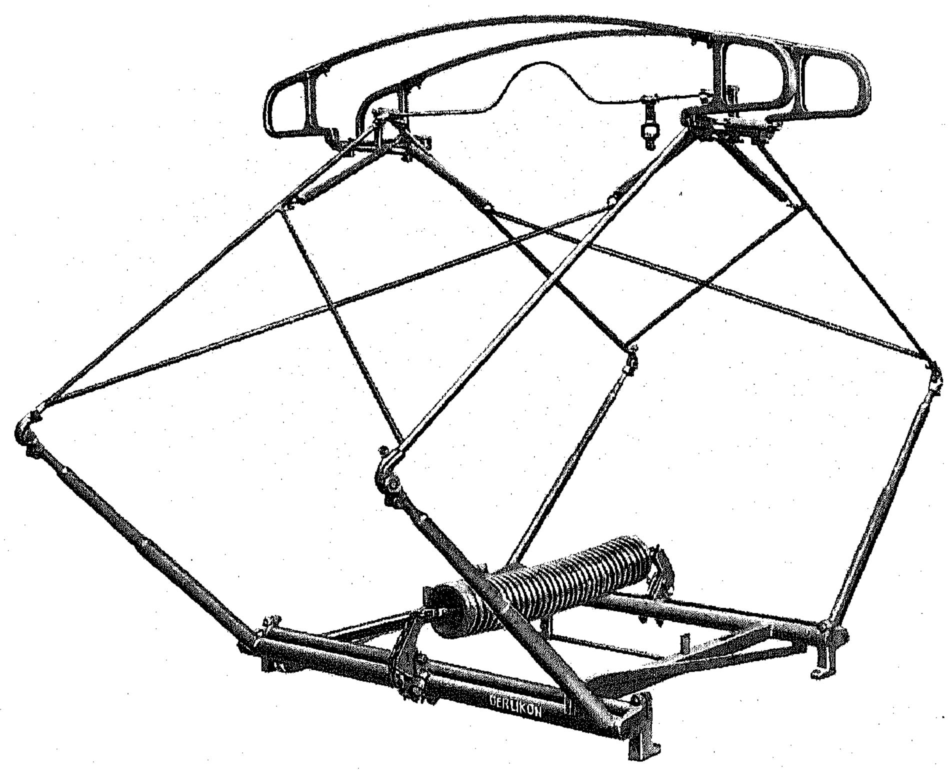


Fig. 9. Pantograph current collector with double bow.

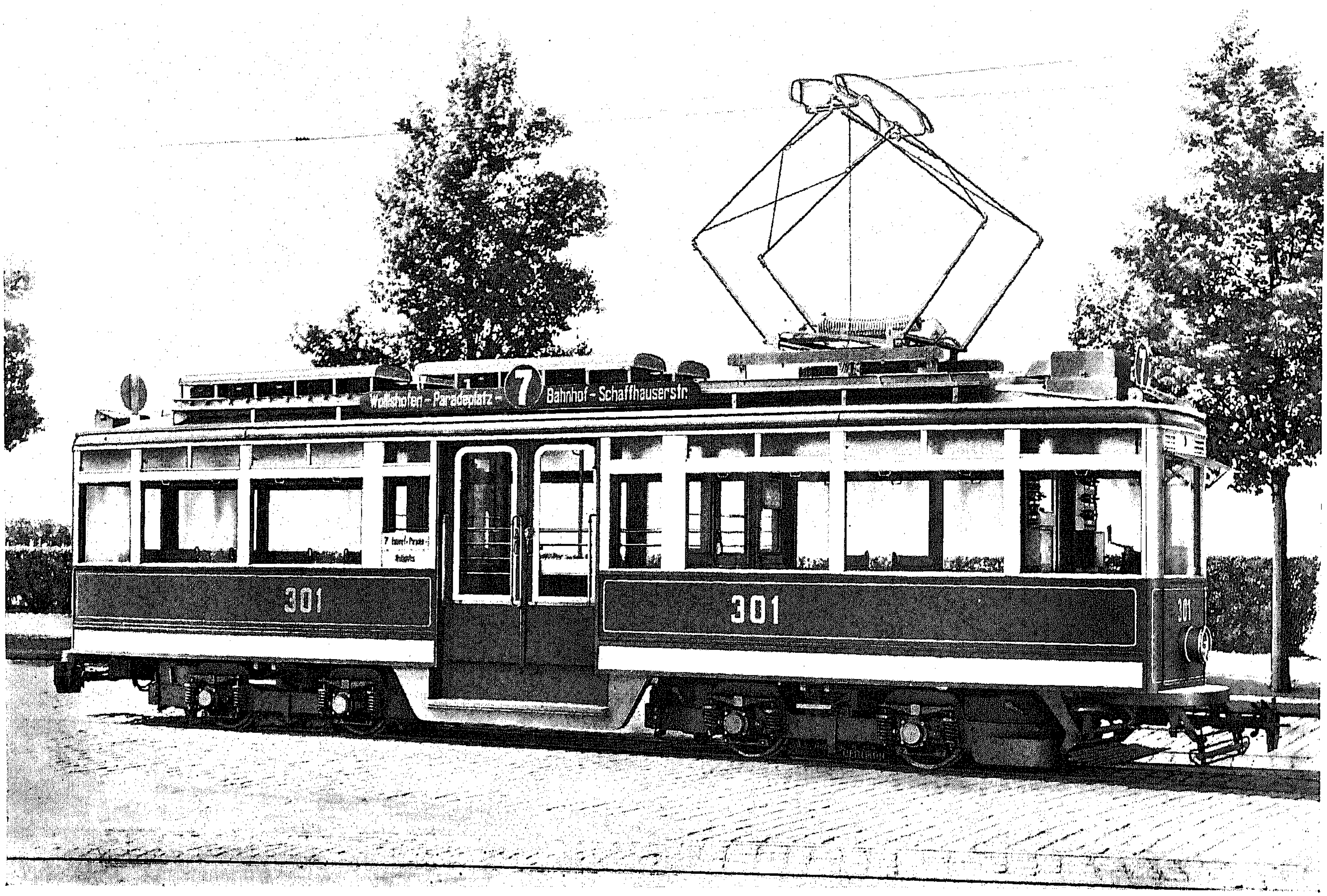


Fig. 10. Four-axle tramcar. Dead-weight 25.2 tons.

of the relatively high motor output, this mode of control was rendered possible, through the use of cam shaft controllers with roller contacts of the Oerlikon pattern. The four motors are grouped in pairs and connected in series or in parallel, during service. In the case of parallel operation, each motor works at full supply pressure. The current peaks when starting on gradients of more than 1 in 14.3, with a train load up to 50 tons, reached values up to 700 amps, which could be dealt with without difficulty, owing to the carefully studied design of contact fingers.

For electric short-circuit braking, all four motors are connected in parallel, in accordance with a new arrangement, whereby „hunting" is eliminated. The change-over drum is so designed that it is only necessary to alter the position of the handle, in order to be able to run or apply electric braking with a single group of two motors, in the case of a defect in a motor.

The current is collected from the overhead line by means of a pantograph current collector with double bow such as shown in Fig. 9. The bow is pressed against the overhead line by means of a spring and is lowered by means of a hemp rope running on pulleys, which is led through a rainproof bushing in the roof to within the reach of the driver.

The starting and braking resistances, which are very amply dimensioned, owing to short circuit braking being utilised on down-grade runs, are built up of cast-iron units and mounted on the roof under a protective cover. When used for braking purposes, these resistances make it possible to deal with the whole tramcar weight, on all inclines, during service.

The inclines encountered on the Zurich tramway system necessitate the provision of powerful emergency brakes. This function is fulfilled by the electro-magnetic rail brakes. There are two such brakes on each bogie, that is to say, four brakes per tramcar, exerting a total attractive effect of 60 tons. These rail brake magnets can be excited either by the short-circuit current of the motors, by the current from the overhead line, or by the short-circuit current and the current from the overhead line, at will, according to a special arrangement devised by the Oerlikon Company. When the rails are dry, these brakes exert a braking effect of about 4400 lbs, measured in a direction parallel to the rails; in the case of damp rails, the figure can drop to 2850 lbs. When used in conjunction with short-circuit braking or even with the hand brakes, the coach can be brough to a standstill within a short distance, on the steepest inclines of the tramway system.

Notes and News Items.

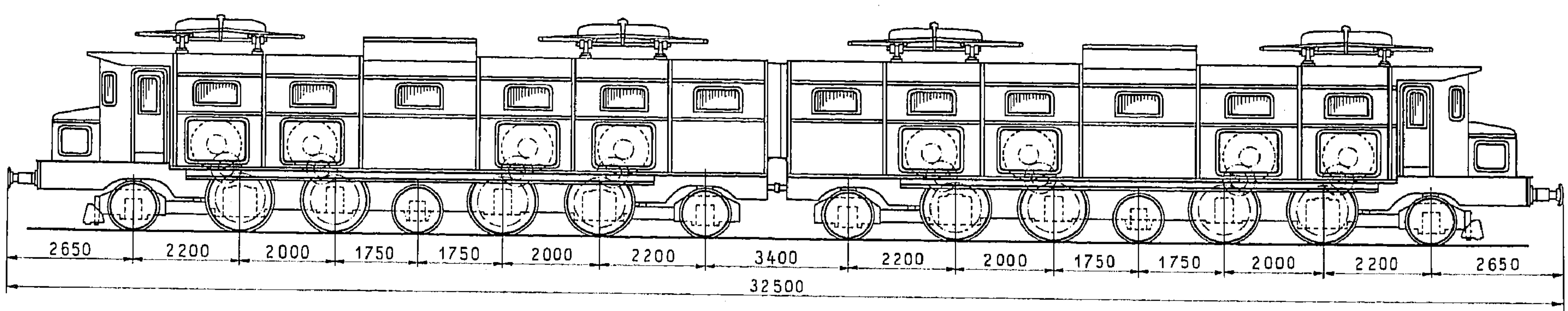
New Orders for Locomotives for the Swiss Federal Railways. Last year the Swiss Federal Railways decided to start on the so-called second stage of electrification 1930—36, covering 305 miles of track; there also was a considerable shortage in locomotives due to the heavy increase in traffic. For these two reasons the Swiss Federal Railways have recently placed a large order for electric locomotives with the Swiss engineering industry.

The order received by the Oerlikon Company comprises the electrical equipments of the following locomotives:

10 locomotives type Ae 4/7 I ($2 D_0 1$) with contactor control,
7 „ „ Ae 4/7 I ($2 D_0 1$) with step switch control,
1 „ „ Ae 8/14 ($1 B_0 1 B_0 1 + 1 B_0 1 B_0 1$) with H. T. control.

Reference has already been made, in a previous issue, to the locomotives type Ae 4/7 I ($2 D_0 1$). In the case of the new Oerlikon locomotives of this type and also of the 19 further ones to be supplied by other Swiss firms, the

Maximum speed, m.p.h.	62
Total gear ratio	1 : 3.47
Diameter of driving wheels	1350 mm (4′ 5.14″)
Diameter of carrying wheels	950 mm (3′ 1.4″)
Wheel base of half locomotive	11.9 m (39′ 5″)
Wheel base of the double locomotive	27.2 m (89′ 2.8″)
Length over buffers	32.5 m (106′ 7.5″)
Weight of the electrical equipment, including regenerative plant and compressor, approx.	107.7 tons
Weight of the mechanical part, including compressed air brake, approx.	121.3 tons
Train staff, and stores such as oil, sand, etc., approx.	1.2 tons
Weight in working order, approx.	230 tons
Adhesive weight, approx.	153 tons
Distribution of axial pressure for each half locomotive	12.3+2×19.2+13.7+2×19.2+12.3 tons
Type	1 B_0 1 B_0 1



Oerlikon design of traction motor which has proved, for many years, very satisfactory, was prescribed. On the other hand, the good results obtained with the new type of Oerlikon contactor control [1]) provided on the two locomotives, type $2 D_0 1$, Nos. 10917/18, have led to the adoption of this mode of control for ten of the new locomotives.

We propose to give here a few particulars regarding the locomotive, type $1 B_0 1 B_0 1 + 1 B_0 1 B_0 1$ (Series Ae 8/14, No. 11851), as this should be of special interest, seeing that it is the most powerful locomotive ever built up to now on the Continent. The accompanying outline drawing shows the general arrangement of the locomotive, while the main data are contained in the following table:

Pressure at overhead line, average	15,000 volts.
Frequency	16—2/3 cycles.
Gauge of track	1435 mm (4′ 8 1/2″)
Radius of curves, smallest, on open track	590 ft.
at points	373 ft.

	One-hour rating	One-hour rating	Continuous rating
Output of driving motors, measured at shaft HP	7200	6560	6560
KW	5300	4800	4800
Corresponding speed, m.p.h. approx.	38.5	31	41.3
Corresponding tractive effort at wheel rim, lbs. [3])	69200	78050	58650
Maximum tractive effort when starting, at wheel rim, lbs.	141100		

[1]) Bulletin Oerlikon No. 97 of July 1929.
[2]) Bulletin Oerlikon No. 77 of November 1927.
[3]) Without taking into account the gear losses.

The locomotive is to be built as a double locomotive, as shown in the sketch, the two halves being close coupled and a driver's cab being arranged at either end behind the hood-shaped extensions. A step transformer together with built-on gear for the H. T. control is mounted over either of the two middle carrying axles. The two outer and the two inner carrying axles are grouped with the adjoining driving axles so as to form separate bogies, respectively. In order to ensure good running qualities on curves, the driving axles have each a side play of 2×20 mm (2×.787″) and the two middle carrying axles a side play of 2×30 mm (2×1.18″).

The locomotive halves are interchangeable mechanically. There are, however, certain parts of the electrical equipment which are only provided singly, for instance, the main circuit breaker, the compressor set and the generator for the supply of the lighting and control circuits, and its regulating gear. The electrical equipment is so designed that these parts can be fitted and connected either on one or on the other half of the locomotive, as desired.

The torque of the driving motors is transmitted to the axles by means of the so-called "Universal" individual axle drive of the Swiss Locomotive and Machine Works of Winterthur — the suppliers of the mechanical part which embodies double reduction gear.

The motors are cooled by forced ventilation and number 16 in all; they are arranged two over each driving axle, on one side in relation to the latter, and with their pinions placed towards the longitudinal axis of the locomotive and the "Universal" drive.

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The Oerlikon Company were entrusted with the designing and supply of these motors and of the motor coach motors referred to below, in view of the very satisfactory results obtained during many years' service with the various new designs of motors of this description [1]), with regard both to long life of commutator and small wear of brushes, and of the fact that they proved entirely immune from the danger of flash-over in the event of the highest pressure fluctuations and heaviest current rushes.

As the locomotives are intended for the St. Gotthard line, which comprises very steep gradients, they are equipped for regenerative braking, by the Oerlikon method.

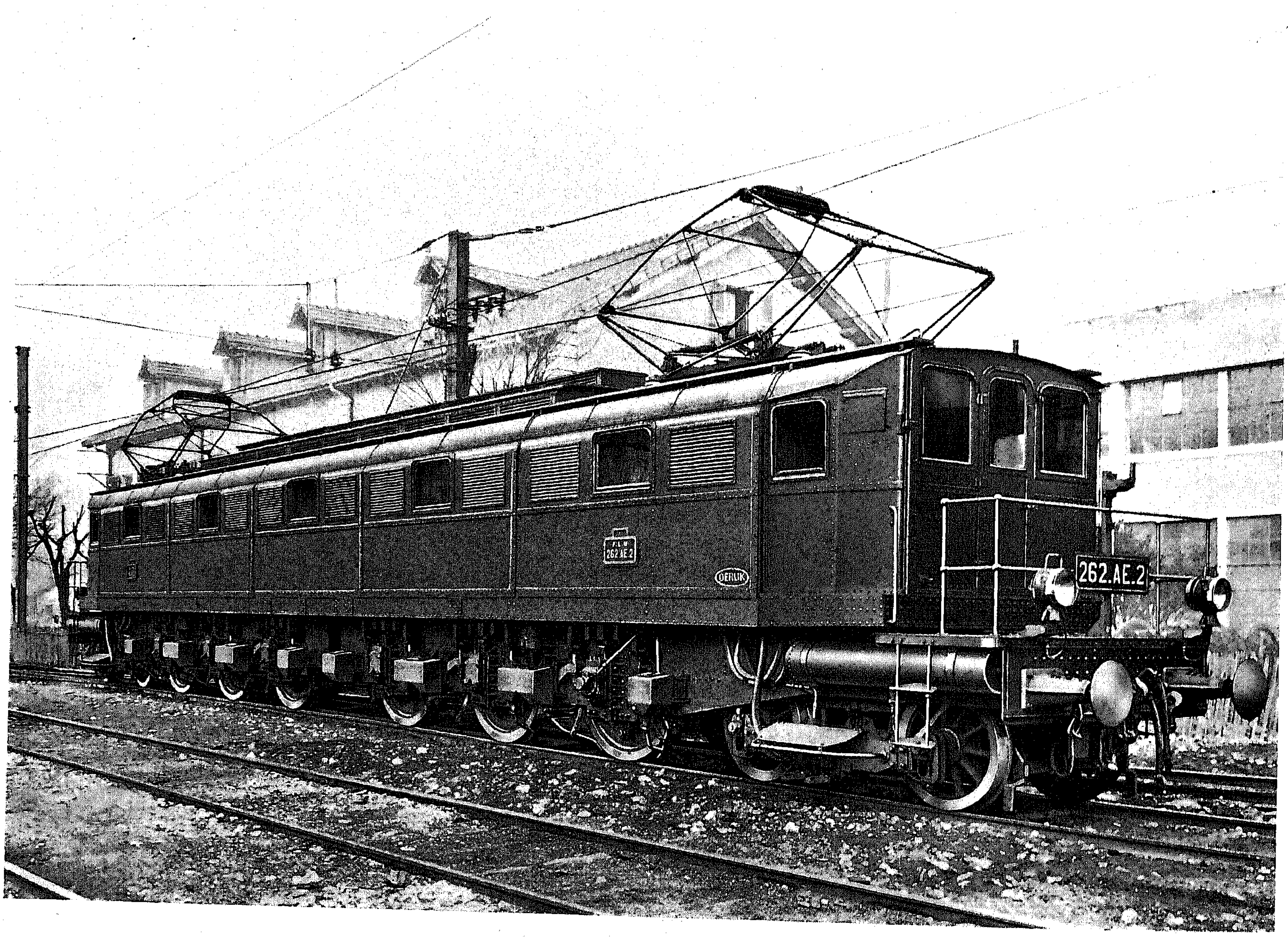
[1]) For instance, the driving motors for the locomotives 2 C_0 1 Nos. 10687-712 and most of the subsequent locomotives 2 D_0 1, for the trial motor coach Fe $^4/_4$ 18561 of the Swiss Federal Railways, for the motor coaches C Fe $^4/_5$, Nos. 721-723 of the Berne-Neuchâtel Railway and, quite recently, for the locomotives Ge $^4/_4$ Nos. 11-15 of the Viège-Zermatt Railway.

It will be seen from the accompanying illustration that the locomotive has four current collectors. The operating gear for the latter is arranged for the operation of only three of these current collectors from the driver's cab, under normal conditions, the fourth being used as a standby.

In addition to these locomotive equipments, the Oerlikon Company have also in hand, at the present time, the following equipments:

8 Driving motors to replace the obsolete motors on the motor coaches Ce $^4/_4$ Nos. 9701/02 and

8 Regenerative braking equipments to be fitted on the motor coaches Fe $^4/_4$, No. 18501 and following, of the Swiss Federal Railways, intended for the lines of the Seetal after their reconstruction.



EXPRESS LOCOMOTIVE, TYPE 2$C_0C_0$2, OF THE P.L.M. RAILWAY
IN FRONT OF THE CHAMBÉRY LOCOMOTIVE SHEDS.

5400 HP. — 80 mph. — 1500 volts D. C. — Oerlikon individual axle drive.

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BULLETIN OERLIKON

No. 108 — June 1930

Oerlikon Mercury Rectifier Equipments.

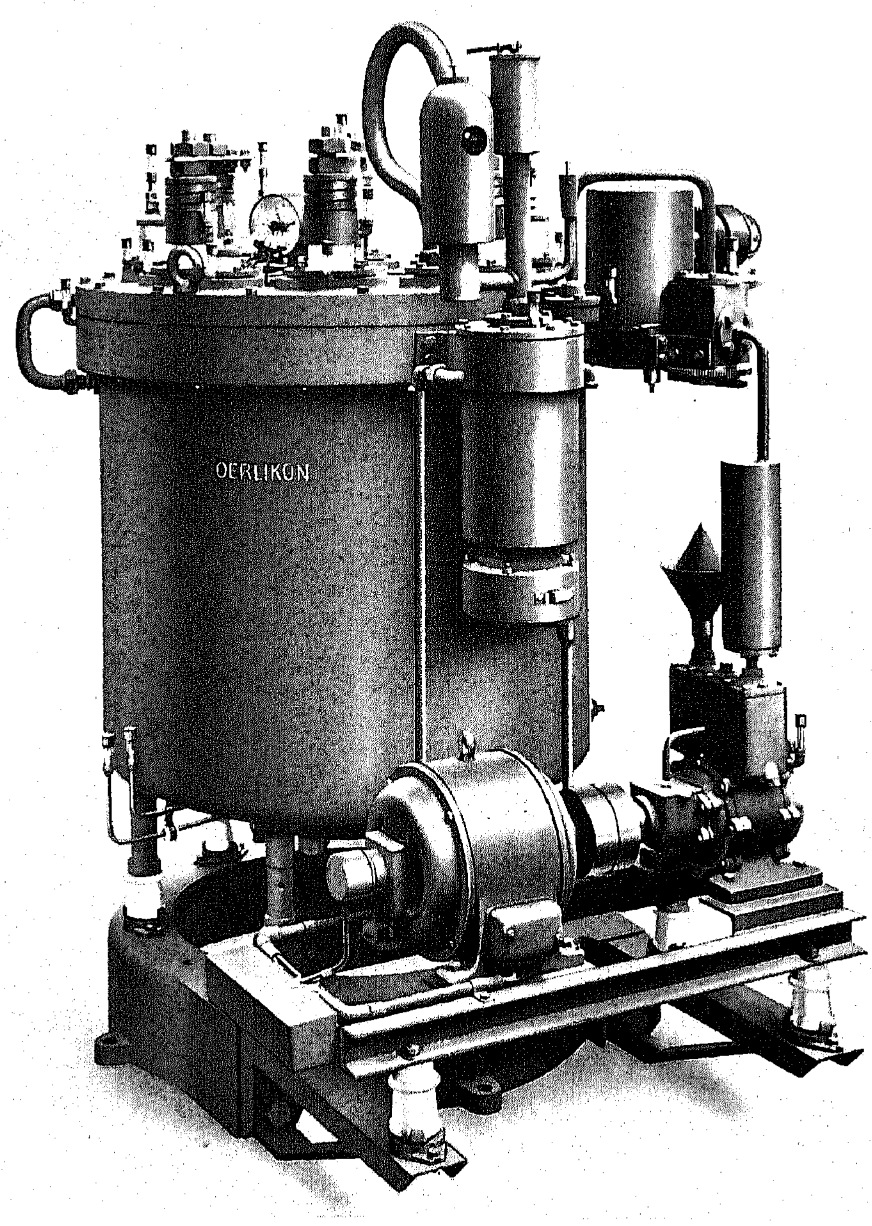


Fig. 1.

In Bulletin No. 96 of June 1929, we described the fundamental principles underlying the design of our mercury rectifiers. Since the publication of this article, a series of new designs have been evolved which have proved very satisfactory in service, and are to serve as standard equipments.

Owing to the fact that the Oerlikon Company have spared no effort with a view to producing special gear thoroughly adapted to the particular conditions connected with the operation of mercury rectifiers and complying with the various requirements laid down, without adhering too strictly to what had previously been done, they have been able to simplify very considerably the apparatus and switchgear, with the result that their mercury rectifier equipments are foremost as regards simplicity of design, safety in operation and easy supervision.

We are describing here, various designs resorted to for our mercury rectifier equipments and are dealing, in particular, with the gear required for automatic operation.

1) Mercury Rectifier.

The design of our mercury rectifiers — apart from a few small modifications — has remained unaltered and has proved entirely satisfactory in a number of installations now working. In view of the fact that the pump set is mounted directly on the rectifier, the erection of plant is simplified and a considerable saving in space is secured. Fig. 1 shows one of our standard rectifiers of the 6-anode type, which is used for currents up to 1000 amps. A 12-anode unit has also been designed on the same lines as the 6-anode rectifier, for larger currents (Fig. 20).

2) Transformers.

A special advantage of mercury rectifiers resides in the fact that the pressure drop under load is small; this means that, as a rule, additional pressure regulation is superfluous. The design with six-phase-Y connection on the secondary side, such as normally used by the Oerlikon Company gives, with a constant primary pressure, a pressure drop of about 5 % for a variation in load from light load to full-load, while in the case of six-phase zigzag connection, this value can actually be reduced to below 4 %. All rectifier transformers are provided with several tappings which can be changed over when no current is flowing; these tappings permit of the adjustment of the D. C. pressure to the conditions of operation. In cases where the pressure has to be regulated during service, this can be done either by means of an induction regulator connected on the primary side of transformer or by means of a step switch and tappings on the transformer.

3) Cooling Equipment.

In all cases where the quality of water is not such as to permit of the cooling of the mercury rectifier directly by fresh water, the plant is cooled by means of water circulating in a closed circuit, in which an intermediate cooler is inserted, the latter cooler being cooled itself either by air or by fresh water. This arrangement is primarily intended to prevent the formation of scale in the water-jacket of the rectifier.

When air is used as cooling medium, there is the further important advantage that the operation of plant is no longer dependent upon the water supply; this is a necessary condition specially in the case of automatic installations, and in districts poor in water.

The first consideration with regard to the latter mode of cooling is that it should not necessitate too large an expenditure of power, and thus impair the main advantage of mercury rectifiers, namely their high efficiency. This requirement is satisfied, to an extensive degree, in the case of the arrangement adopted by the Oerlikon Company, which at the same time permits of a simple and robust design; the arrangement in question presents further the advantage that it eliminates all danger of choking of the air channels by dust or foreign matter, a trouble which may occur, for instance, with plate type coolers.

The plant represented in Fig. 2 consists of a number of cylinders with hollow walls, arranged concentrically, between which the air is driven by means of a helical fan. The circulating pump which causes the circulation of water through the hollow walls of the cylinders is driven by the same motor as the fan. A low power consumption is obtained with this cooler owing to the fact that in the first place the resistance to the passage of air in the latter is small and that, on the other hand, the air leaving the fan flows along a helical path through the cooler. In view of this, the tangential component of the velocity of air, when the latter leaves the fan wheel, which would otherwise be lost, is utilised in connection with the cooling process. The cooling is regulated by switching on and off the motor of the cooler by a thermo-switch which is brought into play through the action of the temperature of the rectifier. The coolers of this design are insulated from earth so that all current leakage to earth through the cooling water pipes is avoided. Fig. 3 represents a cooler such as used in installations where water is utilised for cooling purposes. This cooler is of the multi-tubular type and can easily be cleaned.

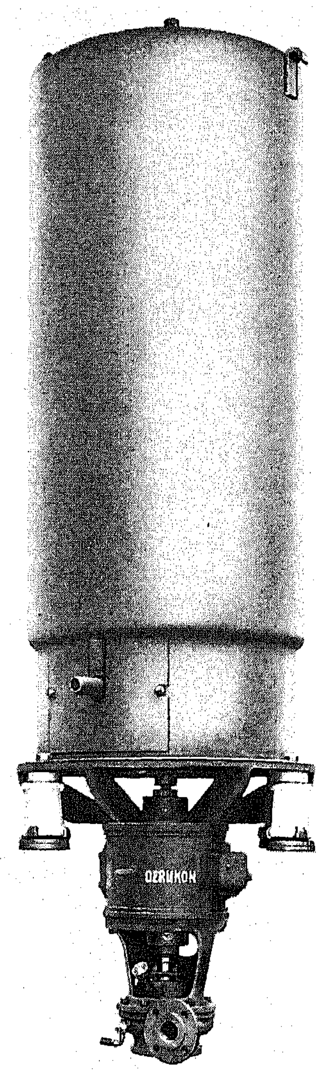
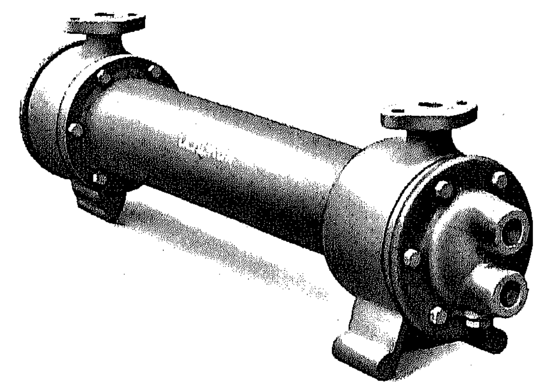


Fig. 2.


Fig. 3.

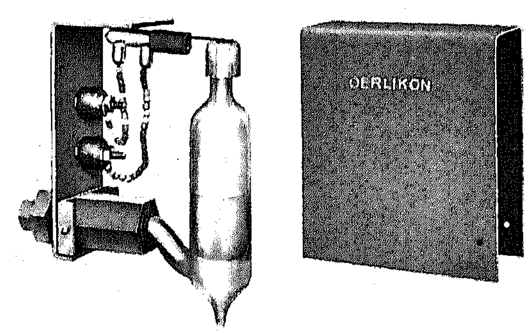


Fig. 4.

Fig. 4 represents an apparatus for checking the flow of cooling water. When the quantity of water decreases below

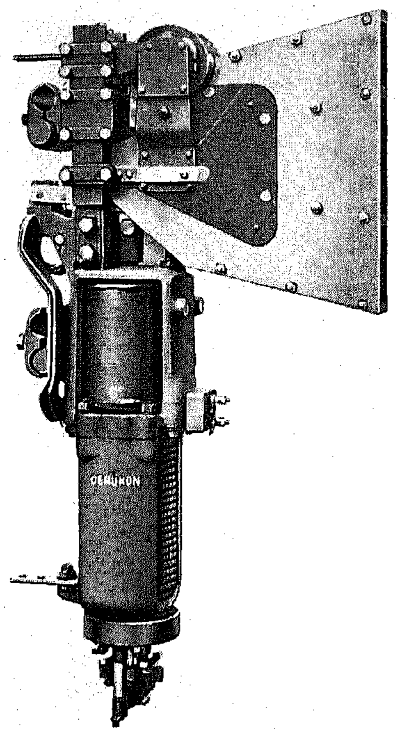


Fig. 5.

a certain value, a float arranged in a glass cylinder having below the shape of a nozzle operates a signalling contact.

4) D. C. Circuit Breaker.

Protection against short-circuits on the D. C. side is a matter of the greatest importance for the safety of operation of rectifier plant, specially in the case of railway installations. In order to prevent interference with the operation of plant, it is necessary to ensure that a short-circuit is interrupted, in the shortest time, on the D. C. side, without this entailing the release of the H. T. circuit breaker. As, however, the latter circuit breaker is usually also designed for instantaneous release without any damping arrangement, this requirement imposes on the D. C. circuit breaker very severe conditions as regards rapidity of motion and rupturing capacity. The Oerlikon Company have evolved, in this connection, a type of circuit breaker which fulfils these conditions in a very large measure and is, at the same time, characterised by its simple and robust design and by the small space it requires. Fig. 6 shows the principles upon which the design of this circuit breaker is based and the mode of connection. The circuit breaker has a permanently excited switching-in and holding coil, 1, and a switching-off coil, 2, energised by the main current; it further comprises a core, 3, linked up to the contact gear of circuit breaker, which is subjected to the action of both coils and an auxiliary core, 4, which can move freely, inserted between the core, 3, and the holding magnet. Owing to the special shape of the casing of the magnet, the main core, 3, separates from the auxiliary core, 4, at the moment the current assumes an excessive value, in which case the lines of force of the holding magnet can close directly without having to pass through the main core. Owing to this, the force exerted by the holding magnet on the main core and, consequently, on the lever of the circuit breaker when switching off vanishes entirely. This causes a rapid switching off and prevents effectively accidental re-switching after the disappearance of the main current (i. e. "hunting"). The re-switching takes place owing to the holding current being cut off and switched on again. This causes the auxiliary core to fall away from the holding magnet and to join up again with the main core; at the same time, owing to the action of the flux which also passes partly through the main core, the auxiliary core carries along with it the main core, when the holding coil is switched on again, with the result that the circuit breaker is closed. If there is again an overload at the moment of switching in, the two cores separate and switching off takes place as described above.

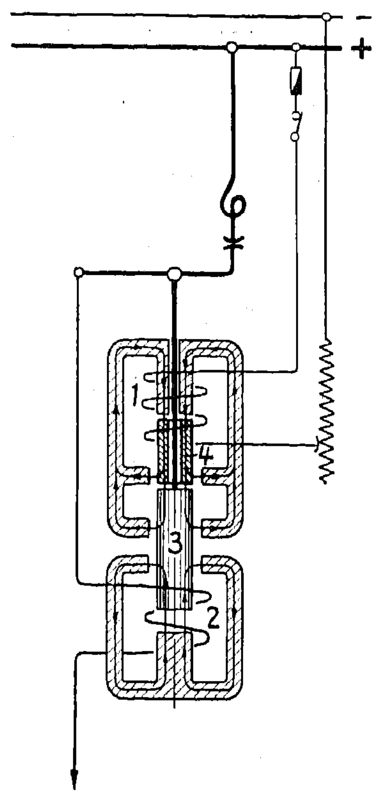


Fig. 6.

1) Holding coil
2) Switching-off coil
3) Main core
4) Auxiliary core

It is possible, by dimensioning the cores specially for the purpose, to make the value for which the release takes place at the moment of switching-in considerably lower than under normal service conditions. This causes a more rapid opening of circuit breaker than would normally be the case when closing the circuit breaker on an overload; in view of this, a line can, in certain cases, be switched on again directly after the release, without danger and without testing the line for short-circuits. This permits, specially in the case of automatic installations, of a very simple arrangement for the control of the automatic circuit breakers of the outgoing lines. Owing to the fact that the holding and switching-in coil is connected to the D. C. supply, it also acts as no-volt release. The setting of the automatic circuit breaker is adjusted by varying the holding current by means

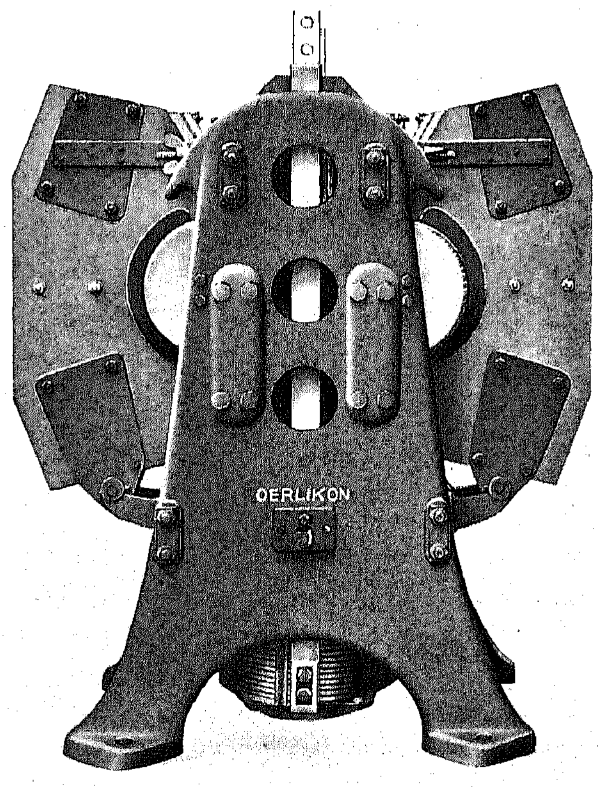


Fig. 7.

of a resistance with sliding contact, specially calibrated for the pressure in question; the adjustment can be made, without danger, under pressure.

Fig. 5 shows a type of circuit breaker built for pressures up to about 1000 volts, while Fig. 7 represents a circuit breaker such as used for pressures up to 1800 volts. We have reproduced in Figs. 8 and 9 oscillograms taken during the interruption of short-circuits at a pressure of 750 and 1690 volts, respectively. It may be mentioned that this type of circuit breaker has the same opening speed for either direction of flow of current, this being an important feature when several units are working in parallel.

Owing to the provision of a powerful blow-out coil and ed and the contacts themselves can be built for currents with so large a value that the switchgear in question can be controlled directly without using intermediate relays.

In the case of automatic substations, the relays serving for the control of the automatic circuit breakers play a very important part. The type of relay used for causing the re-switching of D. C. circuit breakers, after the release of gear, for any reason, is shown in Fig. 11; this relay is wound as a maximum current relay with opening contacts and back-locking device. The relay is in series with the D. C. circuit breaker to be controlled and opens its contacts in the case of a current somewhat lower than that for which the release of the circuit breaker takes place. In the case of an overload,

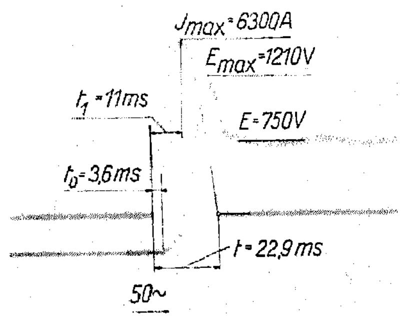


Fig. 8.

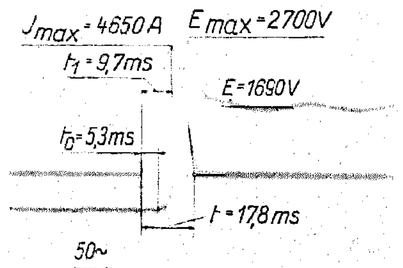


Fig. 9.

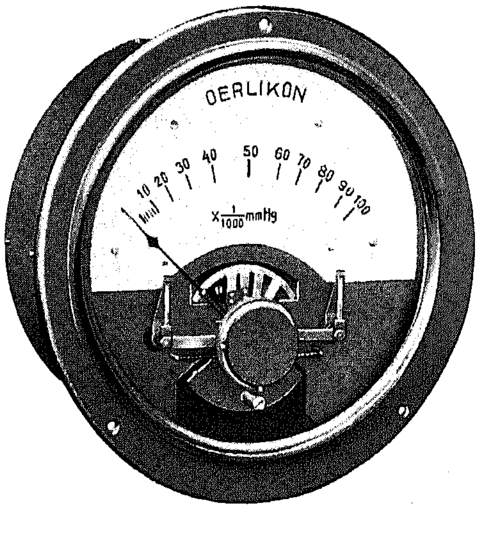


Fig. 10.

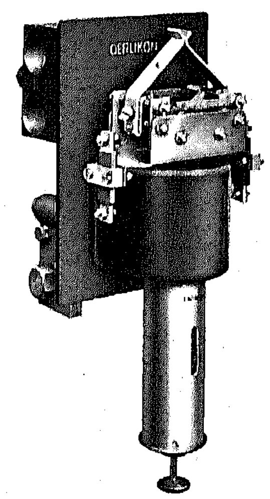


Fig. 11.

to the adoption of a high contact pressure, the wear of contacts is small, and reliable operation of circuit breaker is ensured with as little attendance as possible. During tests carried out with a trial circuit breaker, this gear withstood easily more than 1000 dead shorts, without the wear of contacts reaching 1 mm., a current of 6000 to 7000 amps at 750 volts being interrupted in each case.

5) Relays and auxiliary gear.

The most important part of the mercury rectifier equipments is the vacuum gauge. The principle underlying the design of the Oerlikon vacuum gauge has been described in Bulletin No. 96. This instrument has given very good results and is now also utilised as contact device for the control of the pump and for the alarm signal.

The instrument shown in Fig. 10 is provided with a drop-fork contact — a design of contact which has proved very satisfactory. The pointer of this instrument, together with the contact device is pressed against fixed contact segments by means of a small motor, and released again periodically. This contact arrangement presents the important advantage that, quite apart from the fact that the torque of the indicating instrument is relatively small, good contact is ensur- the circuit breaker itself interrupts, by means of an auxiliary contact, the circuit of the combined switching-in and holding coil; the re-switching takes place only when these auxiliary contacts are bridged over by the contacts of the relay represented in Fig. 11, which operate with time lag.

The diagram in Fig. 16 shows two circuit breakers, 7, and, 9, arranged in this way. In the case of the line circuit breaker, 9, the switching is made dependent upon the absence of short-circuits in the line in question, and in the case of the rectifier circuit breaker, 7, upon the excitation of the mercury rectifier. Fig. 12 represents a relay which, after the release of a circuit breaker, causes the re-switching of the gear for a limited number of times within a given period, after which the circuit breaker is locked in the open position, if these switching operations are followed immediately by the release of gear.

Fig. 13 shows the arrangement for the control of an oil circuit breaker with motor remote control, where the re-switching relay is combined with a time switch which causes the switching-in and switching-off of the circuit breaker in question at the desired times of the day.

The relay consists essentially of a vertical spindle driven at a low speed by a motor, which tilts a pivotting mer-

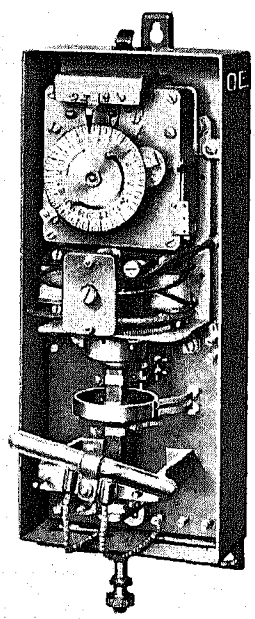


Fig. 12.

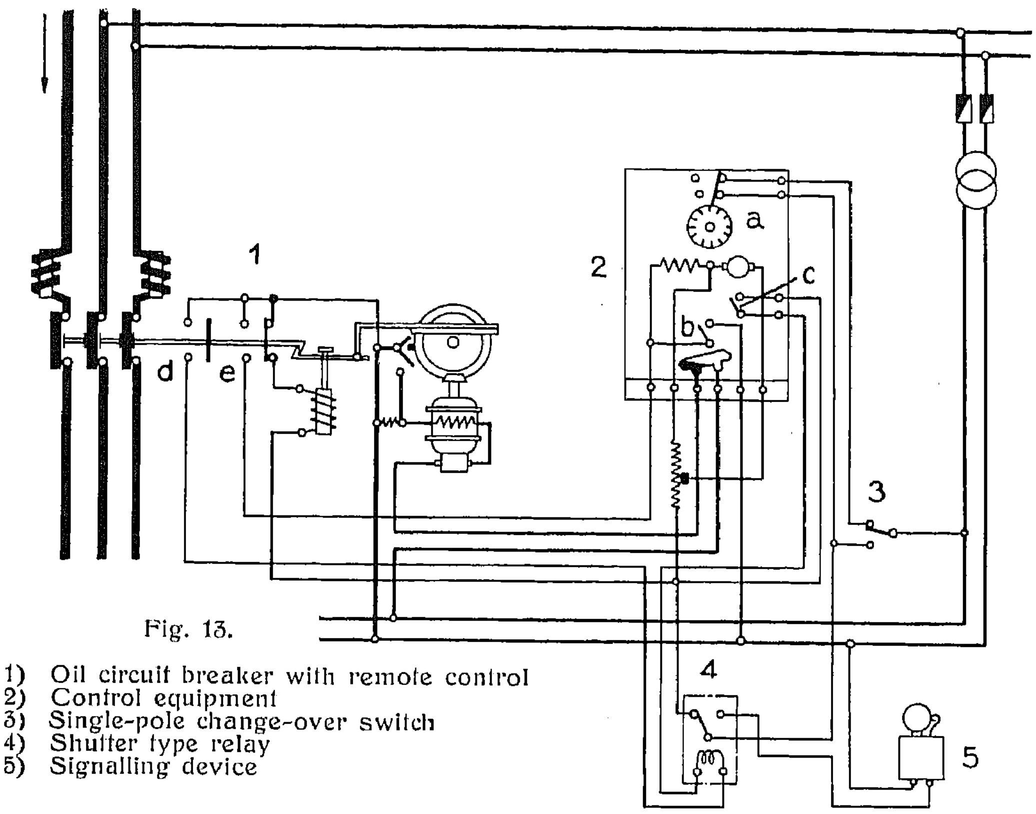


Fig. 13.

1) Oil circuit breaker with remote control
2) Control equipment
3) Single-pole change-over switch
4) Shutter type relay
5) Signalling device

cury contact tube by means of an arm, with the result that the mercury in the tube runs over the contact arranged approximately in the middle of the latter and causes a contact of short duration, which causes the necessary current impulse for the switching-in of the circuit breaker in question.

If, for any reason, the circuit breaker trips, the contact, b, (Fig. 13), which is open in the zero position of the relay, is bridged over by the auxiliary contact, e, of the oil circuit breaker. As a result, the motor of the relay is connected to the supply and starts to drive the spindle carrying the arms. Before the mercury contact tube operates for the first time, the contact, b, closes, with the result that the motor is forced to continue to run, even when the oil circuit breaker is closed and its auxiliary contact, e, is open. Once the mercury contact tube, owing to the impact of the lever, has caused the number of current impulses provided for, and the corresponding switching-in operations have been completed, the relay continues to work when the circuit breaker remains closed, until it reaches the zero position where the contact, b, opens again and the driving motor is brought to a standstill. If, however, the oil circuit breaker trips after the last switching-in impulse, the locking contact, c, comes into play; the latter causes the operation of a shutter type relay by way of the contact, d, of the oil circuit breaker and interrupts the current supply of the motor of the relay while giving, at the same time, a signal. The relay and the circuit breaker are thus locked. The reswitching is done by resetting the shutter type relay in the working position, once the fault has been cleared.

The clockwork shown in the diagram switches on or off, by means of its contact, a, the current supply for the relay and the no-volt coil of the oil circuit breaker, and thus causes the closing and opening of the latter at the desired times. This arrangement is used, for instance, in the case of fully automatic mercury rectifier installations with time control.

It may further be mentioned that the re-switching relay referred to above is suitable, both for alternating current and direct current, and that it does not require an independent current supply. In the event of failure of pressure, the relay remains still and does not cause the locking of the circuit breaker, if this failure is of any duration, as is the case with instruments operated by clockwork. Both the number of re-switching operations and the times can easily be set, at will, during service.

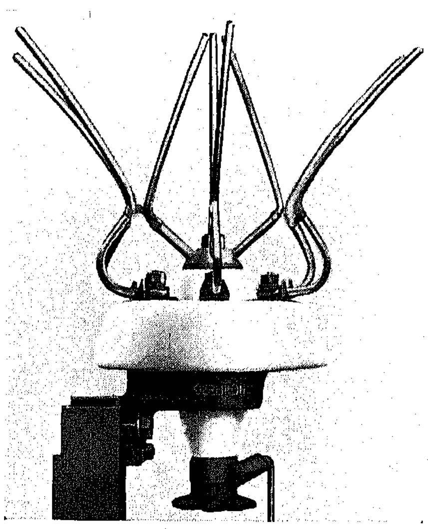


Fig. 14.

Fig. 15 shows the type of relay evolved for use as auxiliary relay for the ignition and for the supervision of the excitation, for signalling purposes, for the control of apparatus, etc. The relays have contacts in the form of mercury contact tubes. These contacts present the great advantage that they never get dirty nor burnt out; furthermore, they can be used up to relatively large rupturing capacities.

The relays are built with any number of poles and are characterised by their very small power consumption and by the absence of noise when the coil is fed with alternating current. The value for which the relay comes into play can be adjusted, at will, by means of a set screw, should this be desired.

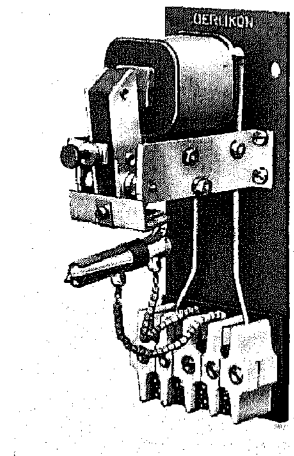


Fig. 15.

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We have previously described the protective gear against surges used for D. C. overhead lines and for contact lines, in particular (Fig. 14). This gear has since proved very satisfactory in a number of installations where it is utilised and, in view of its large current carrying capacity (about 100 amps momentarily) and of the sharp pressure setting, which permits of the adjustment of gear for operation at a pressure as near as desired to the working pressure, it affords for rectifier plant a valuable means of protection against surges on the D. C. side.

We give, in Fig. 16, the diagram of connections of a fully automatic railway installation of our design. The mode of operation of the plant in question is easy to understand by referring to the descriptions previously given of the various types of gear. We propose to deal with it briefly below.

The time switch with re-switching device closes, at the desired moment, the oil circuit breaker, with the result that the rectifier and, at the same time, the ignition and excitation device are put under pressure. The separate ignition winding in the excitation transformer sends a current through the ignition coil of the rectifier, which draws the ignition rod towards the cathode. Once the two have come into contact, a current flows through the ignition rod and the cathode and excites, at the same time, the ignition relay which interrupts the ignition coil. As a result, the ignition rod returns to the position of rest and a spark occurs between the cathode and the ignition rod. This process recurs until the excitation, which is a three-phase excitation, sets in; the excitation current then interrupts the ignition by means of the excitation relay. Part of the excitation current flows through the switching-in and holding coil of the rectifier circuit breaker and closes the latter.

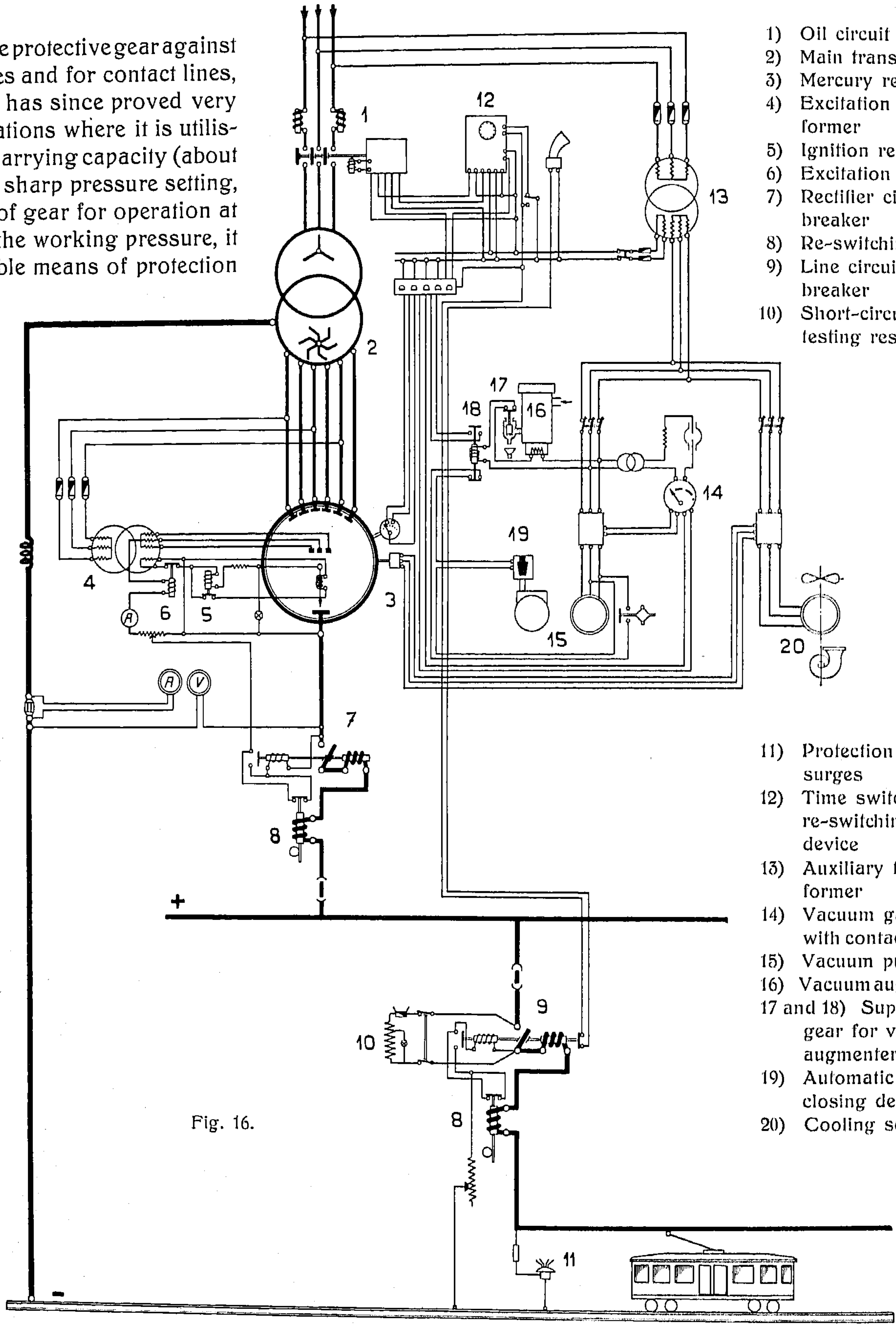


Fig. 16.

1) Oil circuit breaker
2) Main transformer
3) Mercury rectifier
4) Excitation transformer
5) Ignition relay
6) Excitation relay
7) Rectifier circuit breaker
8) Re-switching relay
9) Line circuit breaker
10) Short-circuit testing resistance
11) Protection against surges
12) Time switch with re-switching device
13) Auxiliary transformer
14) Vacuum gauge with contact device
15) Vacuum pump
16) Vacuum augmenter
17 and 18) Supervising gear for vacuum augmenter
19) Automatic vacuum closing device
20) Cooling set

The line circuit breaker closes when the line pressure, which is applied through the short-circuit testing resistance, reaches a sufficient value to enable the switching-in coil connected to the line to close the circuit breaker. The short-circuit testing resistance is so dimensioned that it can remain continuously in circuit, without danger, even in the case of a short-circuit. In order to be able to isolate entirely the line from the busbars, in the case of a permanent short-circuit, a circuit breaker with release dependent upon the temperature of the resistance is connected in series with it. As permanent short-circuits to earth occur relatively seldom, it is sufficient, in most cases, to mount a fuse, which can easily be replaced, on the short-circuit testing resistance itself.

The auxiliaries are fed separately by a small transformer and their operation is independent of the switching-on and switching-off of rectifier.

The vacuum plant is controlled by the vacuum gauge, with contact device, while the cooling set is switched on and off by means of a thermo-contact fitted on the rectifier. The installation comprises normally the following protective devices:—

1) On the three-phase side: maximum current and no-volt release (with automatic re-switching).

2) On the D.C. side: maximum current and no-volt release (with automatic short-circuit testing and re-switching).

3) Device to protect the rectifier against excessive temperature.

4) Device to protect the rectifier in the case of insufficient vacuum.

5) Signalling device which comes into play in the event of disturbances in the vacuum plant.

Any fault that may occur is immediately indicated on a panel with drop-shutters.

The switching on and off of the plant can be done not only by means of a time switch but also by means of remote control; it can further be made dependent upon the value of the current or the pressure of the sets working in parallel or of the overhead line, in which case a further control relay is inserted in the auxiliary circuit.

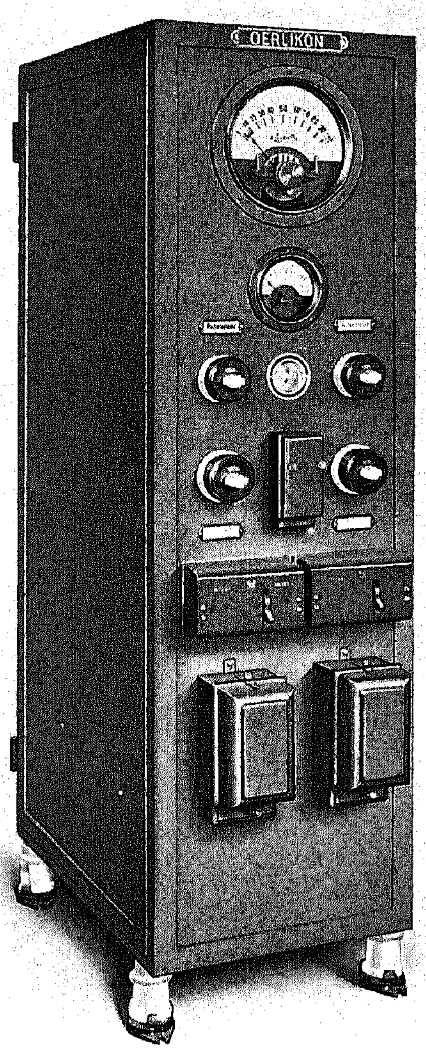


Fig. 17.

6) Arrangement of plant.

In order to have a more uniform arrangement of plant, and, at the same time, with a view to saving space, the Oerlikon Company mount the whole auxiliary gear for the ignition and the excitation, and the control apparatus for the cooling set, and the vacuum plant with the vacuum measuring device, which remain practically the same for all rectifier equipments, in a cubicle insulated from earth, which is arranged next to the rectifier and connected conductively to the latter. This cubicle can be regarded as forming part of the rectifier and is independent of the rest of the switch-gear installation. Owing to the fact that all the above mentioned gear is arranged for automatic operation, it is not necessary under normal conditions to operate, during service, the switches fitted on the cubicle, and the cubicle, like the rectifier itself, is so arranged that it is not possible to come into contact with the plant when the latter is live.

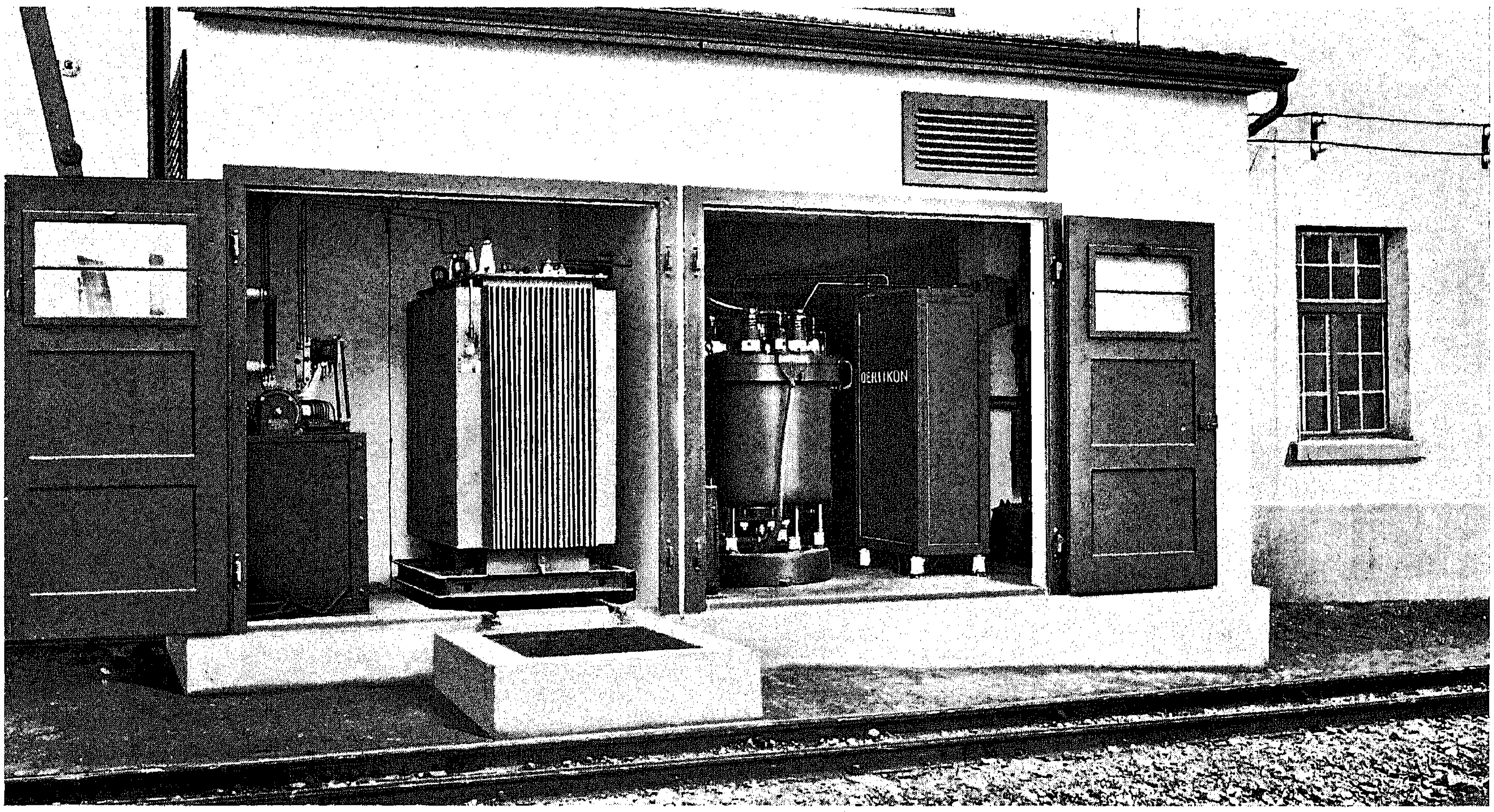


Fig. 18.

As all the auxiliary gear controlling the various circuits is connected directly or indirectly to the casing of rectifier tank and is thus subjected to the D. C. pressure, the fact of insulating it from earth presents a great advantage, as all the gear can remain unaltered in design for all D. C. pressures up to the highest, without this impairing the safety of the plant.

Fig. 17 is a view of the cubicle. In order to be able to operate the switches mounted on it, in the case of emergency, an insulated box spanner is supplied with the equipment.

Another feature is that the auxiliary motors are not protected by means of fuses but by means of a triple-pole automatic circuit breaker with thermal maximum current release. Owing to this, the danger of the motors burning out through running only on one phase, as may happen when fuses are used, is prevented.

As a result of the adoption of the arrangement described for the auxiliary gear of the rectifier, and in view of the fact that our D. C. circuit breakers are all provided with electro-magnetic control, a simpler lay-out of plant is possible and the space required is reduced. The design with pump set mounted on the rectifier and with air cooled water cooler arranged vertically is another factor which has a similar effect.

Fig. 19 shows the arrangement of the D. C. gear of a 500 KW. equipment with two feeder circuit breakers, provided with automatic re-switching device.

Fig. 18 is a view of this plant. The facilities as regards access to plant and supervision can be clearly seen from this illustration.

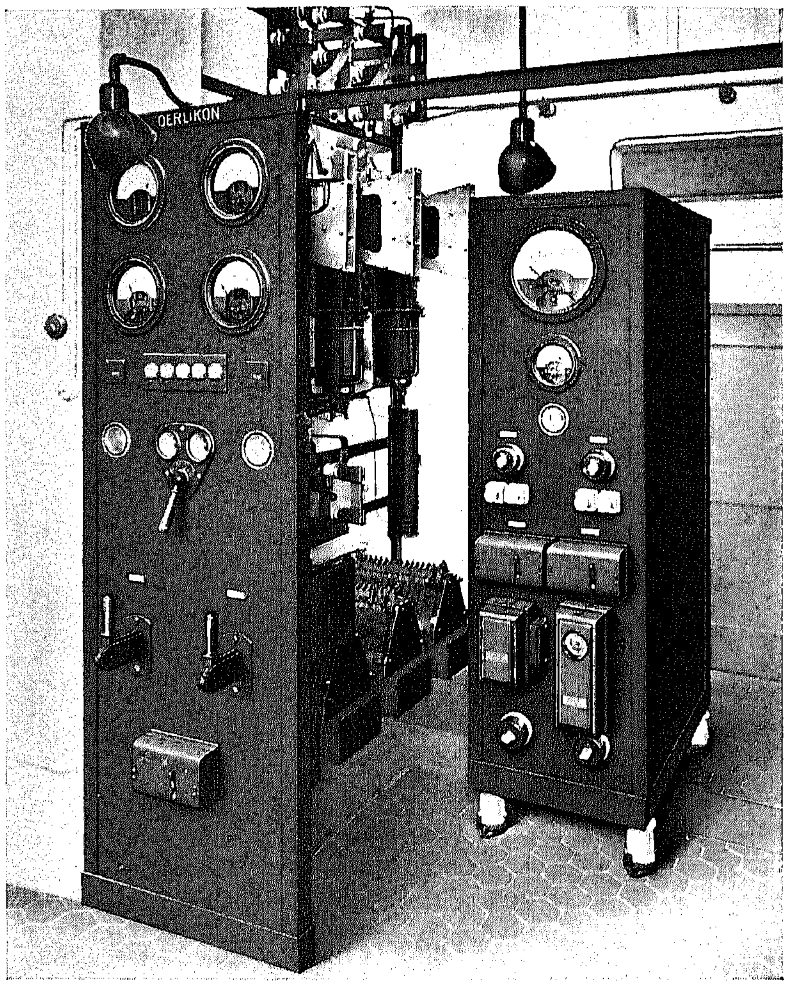


Fig. 19.

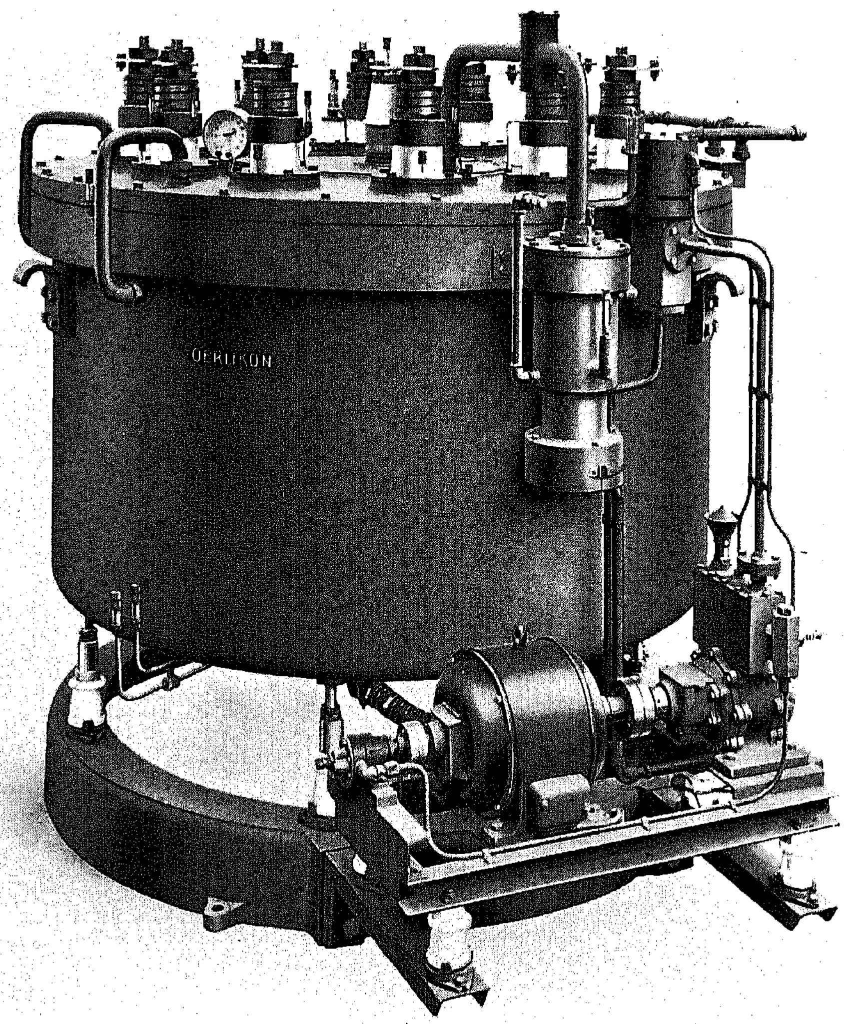


Fig. 20.

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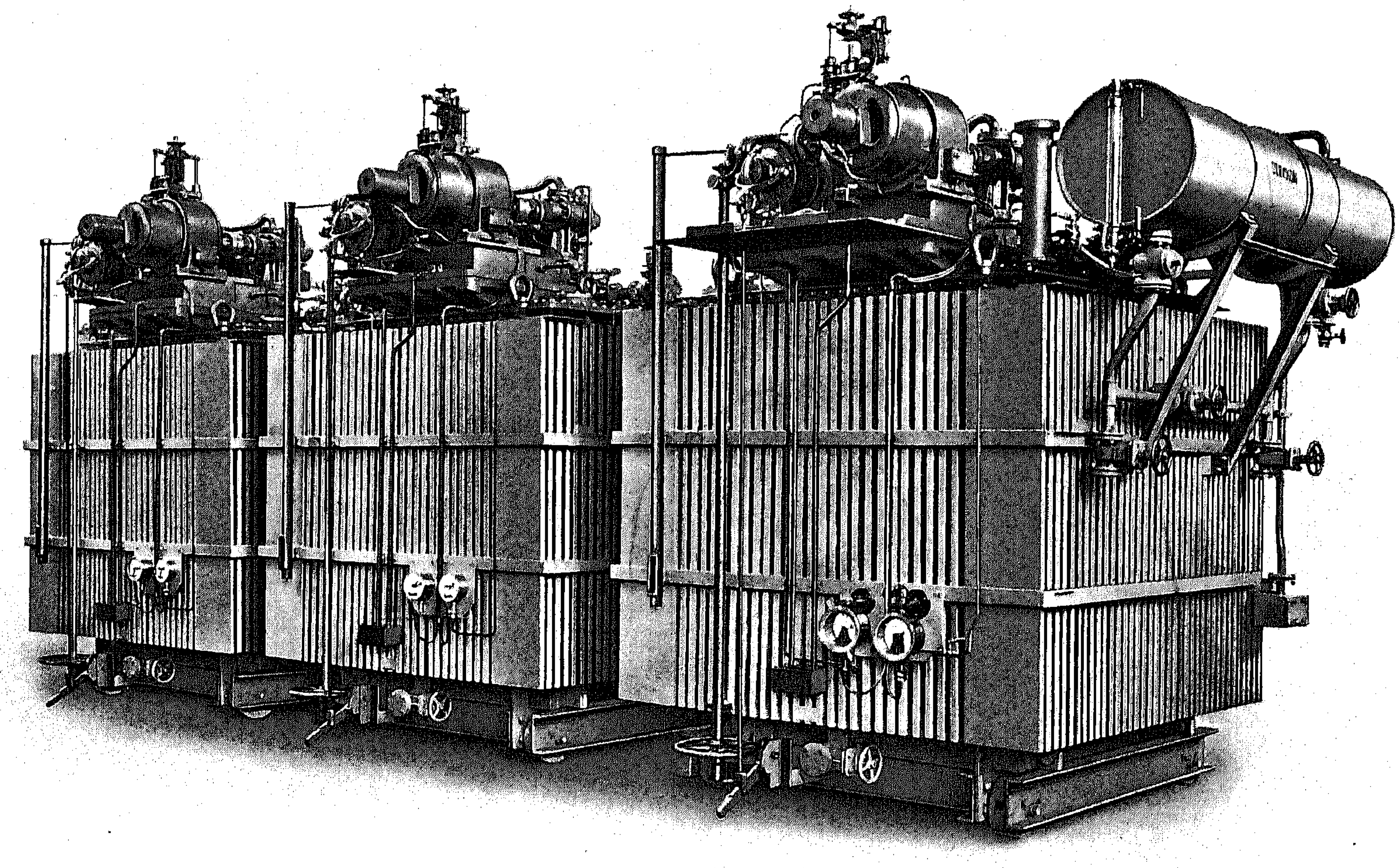


Fig. 1.

Pressure Regulation in Secondary Distribution Systems by means of Induction Regulators.

by J. Kristen, Oerlikon.

Report to the Second World Power Conference, Berlin, 1930.

In Europe, induction regulators have not yet met with the degree of popularity that they deserve. In America, 80% of the distribution systems are, at the present day, equipped with induction regulators for the purpose of regulating the pressure. In Europe, however, there has been of late, in certain quarters, a trend averse to the use of induction regulators, in spite of the fact that this gear is still the only apparatus that permits of the absolute constant regulation of the pressure without any interruption of current. Both the centralisation process in connection with power supply, and the limitation of the short-circuit output by means of transformers with a high reactance have, in recent years, brought the problem of pressure regulation in secondary distribution systems, once more to the forefront in Europe too. At the

same time, a serious competitor has appeared in the form of step-transformers, a type of plant also imported from America. Although the induction regulator is unsurpassed as regards simplicity and reliability, these ideal properties have had to give way to the exigencies of the market, which has demanded ruthless saving in the matter of gear. As the question of price is the factor governing the market, the object aimed at in recent years has been to reduce the price of the induction regulator to the utmost degree, in order to be able to compete successfully with step-transformers.

Very substantial reductions in the price of induction regulators have been secured, on the one hand by increasing the capacity of the different sizes of regulators and, on the other hand, by adopting a mechanical design cheaper to produce. Up to a few years ago, the induction regulators used, in Europe, were, in most cases, designed with 4 poles. At the present day, however, the 2-pole design is being resorted to. In order to be able to judge of the effect of these measures, we shall consider a given induction regulator with a given outer diameter and width of core. With a given diameter of rotor, given slots and copper, this size of induction regulator has a given internal capacity when built of the 4-pole type. If we take this same induction regulator but connect the slot conductors so as to form a 2-pole equipment instead of a 4-pole unit, we then have, in the case of the same saturation of yoke, the same flux in the induction regulator, so that the induction in the air is reduced by half; the same applies to the saturation of teeth. This means that, when the induction regulator is connected as a 2-pole unit and used for the same internal capacity as for 4-pole connection, it is not fully utilised from a magnetical point of view. On the other hand, it may also be said that the percentage light-load current drops to $^1/_4$ of its value and the percentage short-circuit pressure increases 1.6 times, when passing from the 4-pole to the 2-pole design, in the case of the same size of regulator. In order to utilise better the 2-pole design, we now reduce the diameter of the rotor and thus increase the flux of the regulator size in question, while retaining the same saturation in the yoke, until the saturation of the rotor teeth is raised to the limit attained in the case of the 4-pole design. At the same time, the loading in amp-conductors per cm length of periphery rises and in order to keep within the same limit of temperature rise, it is necessary to reduce the saturation of copper (s_k) to such an extent as to ensure that the losses per cm length of periphery (amp-conductors × s_k) remain constant. Both calculation and experience confirm that, with the same magnetic saturation and the same temperature rise, the internal capacity of the same size of induction regulator can be increased in the case of the 2-pole design by about 25—30 %. On the other hand, the general adoption in recent years of alloyed stampings for the construction of electric machines, and of figures up to 14000 gauss for the saturation of yoke has permitted of a further increase in the capacity of induction regulator. As a result of the better magnetic utilisation, the percentage light-load current has been increased and the percentage short-circuit pressure has been reduced, so that in the case of an induction regulator of average capacity and pressure, of the 2-pole type, we can reckon with a light load power component of 0.9 to 1.3 % and with a light load wattless component of 13—17 %. The short-circuit power component reaches a value of 1.7 to 1.8 % and the short-circuit wattless component, a figure of 17 %. It is interesting to compare these values with those for step-

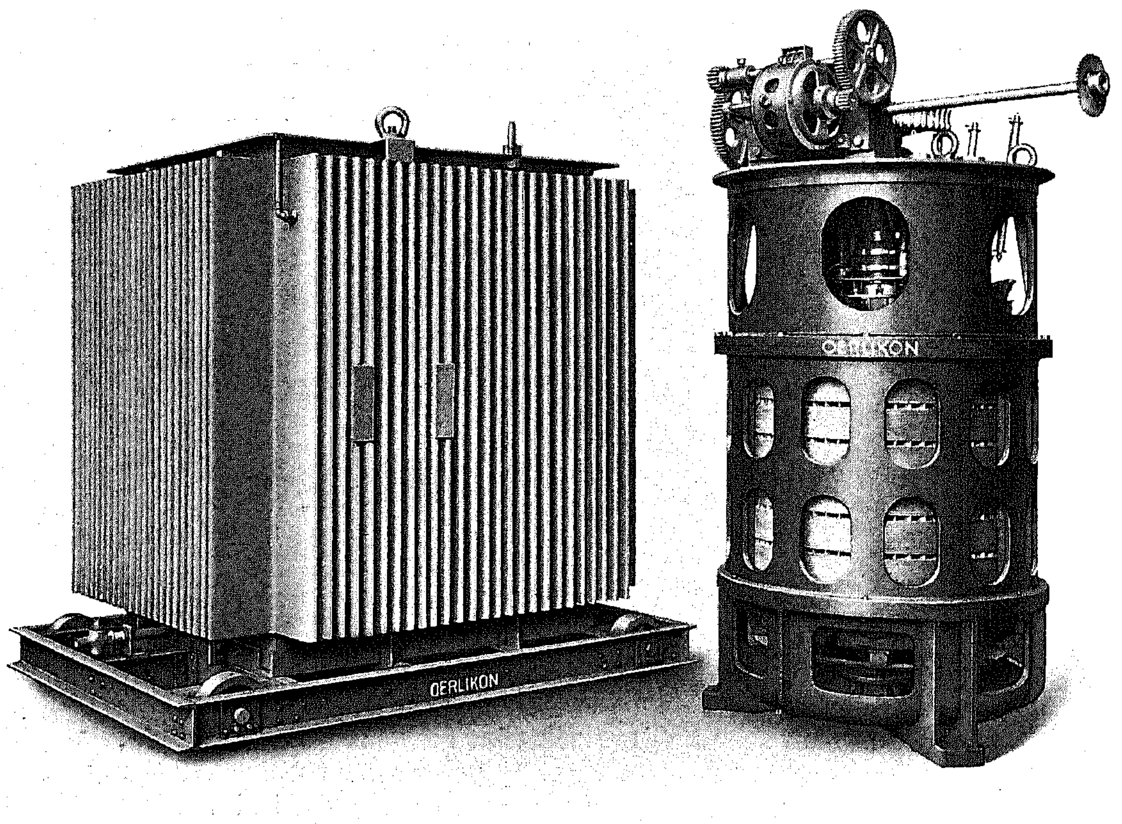


Fig. 2.

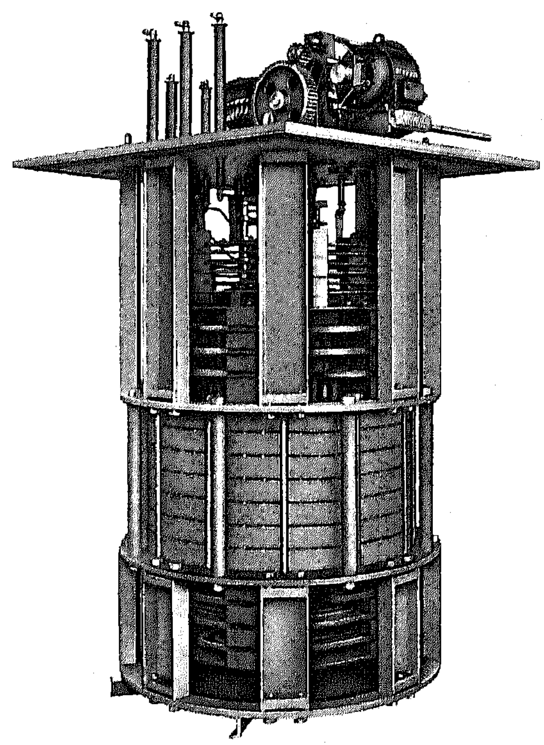


Fig. 3.

transformers also of average capactiy and pressure; the corresponding values of the light load components are here 0.475 and 3.2% and those of the short-circuit components 2.1 and 10.5%, respectively. In this connection, it must be pointed out that the percentage short-circuit pressure has been increased to that value purposely. As regards the losses in these two types of plant, they are about 2 to 3 times larger for induction regulators than for step-transformers, in the case of the light load losses, and practically the same in the case of the short-circuit losses. As, however, for a range of regulation of ±10%, for instance, the values of losses amount, for both types of regulating plant, only to about $^1/_{10}$, when referred to the external capacity, they are of secondary importance as compared with the losses in the generators, power transformers and lines, in particular.

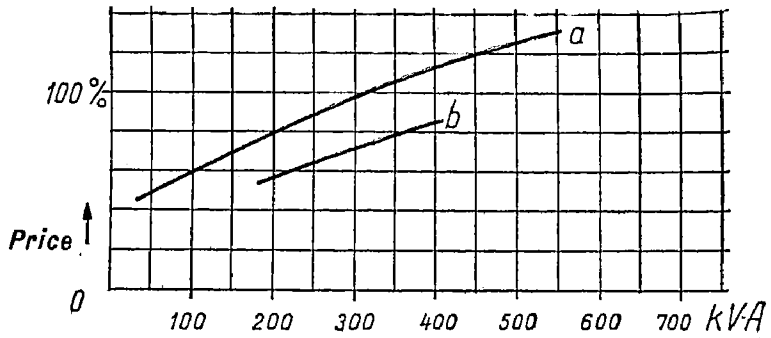


Fig. 4.

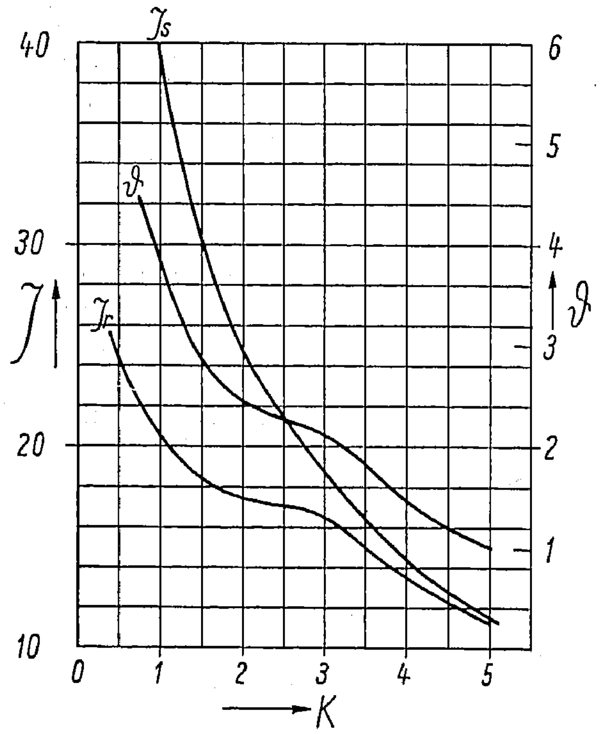
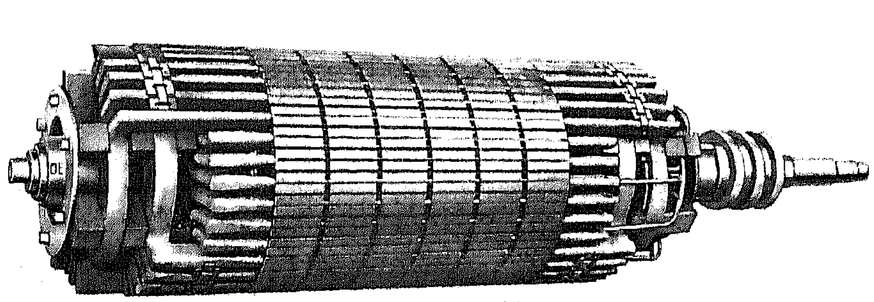
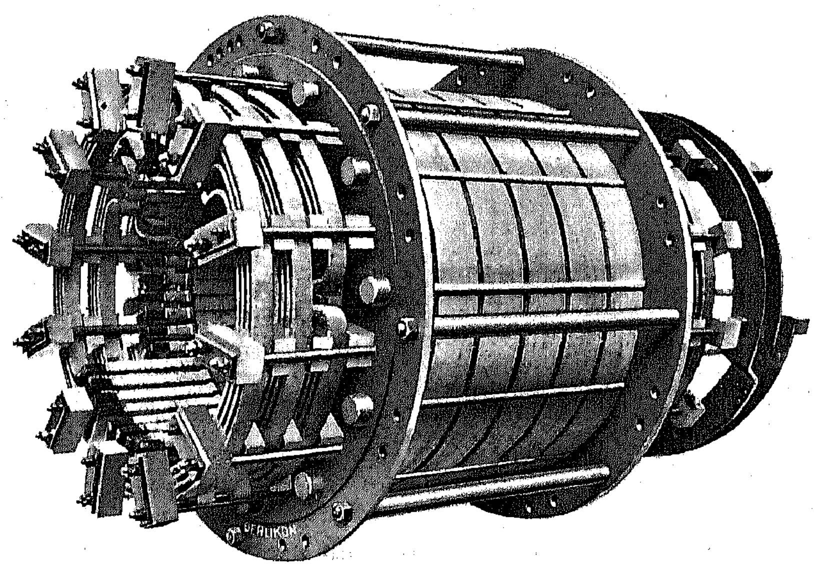


Fig. 7.

As regards the question of construction, it may be mentioned that although the core and the winding of an induction regulator may correspond to those of an induction motor, a design on special lines has been evolved in the course of years. Fig. 2 shows the arrangement where the induction regulator is contained in a cast-iron frame. In recent years, the tendency has been to abandon the design with cast-iron frame and to adopt a mode of construction where rolled iron is used, as, in certain cases, this means a reduction in cost. With this design there is, in first place, the saving in the matter of cost of patterns and foundry charges while, on the other hand, the freight charges and duty are reduced, owing to the reduction in weight. At the same time, the possibility of delivering the plant in a shorter time than induction regulators with cast-iron frame, may often be an important consideration. The fact that induction regulators, in very first place, have been able to benefit by the advantages afforded by a design with rolled iron must be ascribed to the fact that this plant is, in the majority of cases, of the oil-immersed type; this means that a much greater latitude can be allowed with regard to shape in the case of this plant than for machines which are directly visible to the eye. Fig. 3 shows an induction regulator with rolled iron supporting structure.

All the measures we have described here have had the effect of reducing the price of the plant considerably, as can be seen from the curves in Fig. 4, which have been plotted for induction regulators for a working pressure of





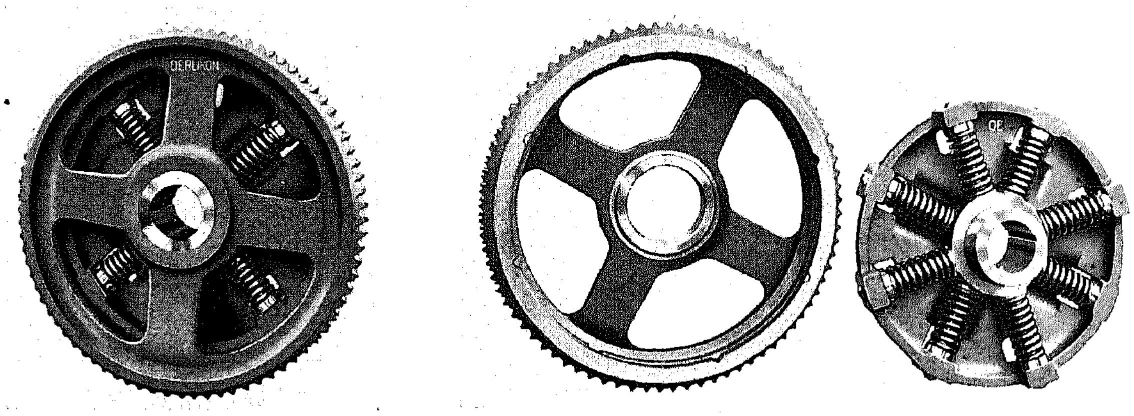
Figs. 5 and 6.

6000 volts. Curve (a) gives the price of induction regulators with two poles of older design with cast-iron frame; Fig. 3 corresponds to a modern two-pole design with rolled iron supporting structure. As the result of this reduction in price there is very little difference in price, in the case of the capacities usually encountered and for working pressures of 6000 to 10,000 volts, between induction regulators and step-transformers. If the working pressure is increased, the step-transformer presents a certain advantage in the matter of price, as the cost of the step-transformer itself and also of the contact gear is not increased to any considerable degree, for pressures of 10,000 to 20,000 volts. There are a certain number of Oerlikon equipments for outdoor mounting, built for a working pressure of 17,500 volts,

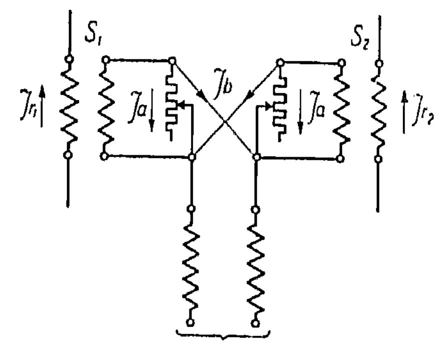
and a range of regulation of $\pm 10\%$, which have been in use for many years in an important overhead distribution system, where they are connected directly in circuit. It can, therefore, be said that, at the present day, all pressures encountered in distribution systems can be dealt with in a reliable way by means of induction regulators connected directly in circuit.

As regards the cooling of induction regulators, provision is made for natural or forced air cooling, in the case of small capacities up to about 20 KVA and for a working pressure of about 2000 volts. From that value, up to the highest capacities, both forced air cooling and natural oil cooling are used. Induction regulators for connecting directly in the distribution systems are nearly without exception designed for natural oil cooling, in accordance with the general practice in connection with modern transformer design; these regulators can thus be used either for indoor or outdoor mounting.

A very important aspect of the design of induction regulators is that relating to the protection of the winding against excessive current. It is a well-known fact that, in the case of short-circuits, induction regulators are subjected to stresses which are very great in comparison with their own capacity. It may further be pointed out here that the step-transformer is in a more unfavourable position in the case of excessive current than the induction regulator, as the former is normally designed for a very much smaller short-circuit pressure. The fact of changing from the four-pole to the two-pole design has, in the case of the same size regulator, practically not altered the loading per cm. length of the ends of coils, as with the four-pole arrangement, the winding is arranged in two tiers and with the two-pole design in three tiers. On the other hand, it must be said that the straight portions of the ends of coils, projecting from the slots, are subjected, in the case of the two-pole design, to forces which are nearly twice as large. For this reason, these portions of coils have also to be held apart by means of distance pieces bound together with the winding or by means of a comb-shaped support. Figs. 5 and 6 show the supporting arrangement such as used on a two-pole induction regulator with rolled iron frame, with a view to rendering it secure against short-circuits. The stresses to which the plant is subjected depends, however, finally upon the location of the induction regulator in the system. In the event of a short-circuit in a distribution system unlimited as regards capacity, the pressure to which the winding in series with the line is subjected, both in an induction regulator and in a step-transformer amounts, in the case of a range of regulation of $\pm 10\%$, for instance, to ten times normal pressure. Under these conditions, a very heavy saturation occurs, of course, and at the same time large magnetising currents are produced; the effect of the latter is to increase still further the short-circuit currents as, owing to the presence of these magnetising currents, the reactance of the rotor winding is lost for part of the stator currents. The current ratio between stator and rotor is greatly altered, so that the rotor currents do not increase to the same degree as the stator currents. If there are further reactances in series, such as, for instance, transformers or lines, they alter the short-circuit conditions in the induction regulator to the extent to which they are comparable with the stator short-circuit reactance of the induction regulator, referred to the load passing through the regulator. The curves in Fig. 7 give the current conditions in the case of a direct three-phase short-circuit, in function of a factor k, which is equal to the quotient of the reactance of system in series ($\mathcal{E}_v$), and of the stator reactance of the induction regulator ($\mathcal{E}_{ks}$). If the reactance of the system $\mathcal{E}_v = 7\%$, we can take a value $k = 4$ and the conditions are not rendered more difficult. If, however, the induction regulator is installed in the neighbourhood of the power station and deals with a relatively small load, we get near the value $k = 1$, in which case it is necessary to pay attention, not only to the heavy mechanical short-circuit stresses, but also to the heating effect in the windings. In such exceptional cases, a protective choking coil can often not be dispensed with.



Figs. 8 and 9.



Pressure circuits of the automatic pressure regulation.

Fig. 10.

With a view to protecting the operating gear of induction regulators, the Oerlikon Company provide the latter with their so-called slip coupling. Figs. 8 and 9 represent a coupling of this type. It is possible by adjusting the springs of the coupling accordingly to arrange that, in the event of an excessive torque, as a result of an overload or of a short-circuit, for instance, the rotor becomes uncoupled from the operating gear, and the shaft and operating gear of regulator are thus protected from damage. In view of the fact that, in such a case, the rotor is released, the Oerlikon Company provide all their induction regulators with sliprings, as shown in Fig. 5. As a rule, the springs of the slip coupling are set for a maximum torque corresponding approximately to $2-2^1/_2$ times normal torque. As regards the mechanical stresses acting on the operating gear, the adoption of the two-pole design has had the effect of considerably

relieving the gear as, for the same internal capacity, the normal torque is reduced by half.

In the case of equipments for automatic pressure regulation, it is important to distribute the whole load over several regulator equipments, firstly for economical reasons, as the load is subject to fluctuations and, secondly with a view to continuity of supply. Thus economical reasons as well as technical considerations lead up to the problem of parallel operation of several induction regulators. If we leave out of consideration the solution where the regulator units are mechanically coupled, owing to its being obsolete, it may be said that the conditions to be satisfied are that the induction regulator units operating in parallel should work synchronously and always occupy the same position. It is only in such a case that the losses in the pressure regulating plant are minimum and that the individual units can be protected against overload. It is in order to satisfy these conditions that provision has been made for the stabilising of the parallel working of induction regulators. The Oerlikon Company realised, at an early date, the importance of this question and devised a stabilising arrangement for induction regulators, which permits of the stabilisation of any number of induction regulators in a purely electrical manner, this being done by using the rotor currents of the induction regulators in conjunction with current transformers arranged according to a kind of polygonal connection. As, in the majority of pressure regulation installations, use is made of single induction regulators (double induction regulators are, in most cases, out of the question owing to their price), we propose to deal in our study with the former type of regulator.

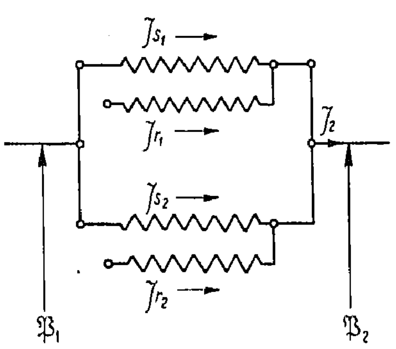


Fig. 11.

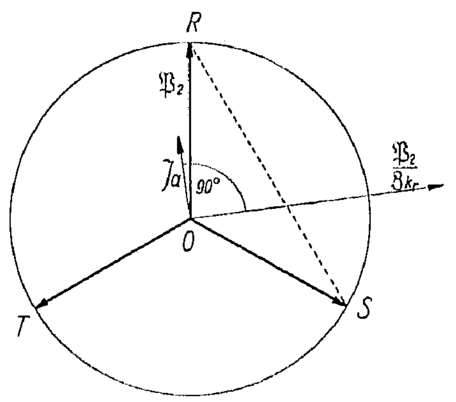


Fig. 12.

As can be seen from Fig. 10, the stabilising equipment consists of current transformers (S_1 and S_2) having their primary windings connected in series with the corresponding rotor phase of the induction regulators working in parallel, whereas the secondary windings are, on the one hand, bridged over by an ohmic regulating resistance and, on the other hand, connected in opposition, from one induction regulator to the other, by means of crossed connections. In Fig. 10, we have taken, for the sake of simplicity, the case of two induction regulators; the arrangement in question can, however, of course, be extended to any number of induction regulators. If the two regulators, working in parallel, are in the same position, the rotor currents are the same and the corresponding secondary currents of the current transformers flow back through the crossed connections; if, however, a relative displacement occurs between the two induction regulators, we have an equalising current which flows in the two regulators in opposite directions. The primary currents of the current transformers can thus be represented by the sum or difference of the two currents; we can write: $J_{r_1} = J_b + J_a$ and $J_{r_2} = J_b - J_a$, where J_b is the portion of current which is the same for both induction regulators and J_a the equalising current. The latter current can be expressed in a simple way as the difference between the rotor currents: $J_{r_1} - J_{r_2} = 2 J_a$. Let us see what occurs on the secondary side of the current transformers. The portion of the secondary current corresponding to the load current J_b flows back through the crossed connections, while the portion corresponding to the equalising current J_a is diverted through the ohmic regulating resistance. The pressure that is produced across the resistance in the case of out-of-balance is applied in the circuit of the pressure coils of the automatic pressure regulator, in the same direction, for the purpose of stabilising the parallel working of the regulators, in such a way that, in the event of out-of-balance, the two regulators are displaced in opposite direction, until the pressure across the regulating resistances and, consequently, the equalising current has disappeared.

It may appear strange, at first sight, that it should be precisely the rotor currents that are used for stabilising purposes. In order to explain this, we shall consider the value and phase displacement of the equalising current. We shall base our remarks on the diagram in Fig. 11. Two single induction regulators are connected in parallel. The stator currents are represented by J_s and the rotor currents by J_r. The pressures before and after the induction regulators are indicated by $\mathfrak{P}_1$ and $\mathfrak{P}_2$ and the load by the current J_2. The position of the rotor, for the time being, is represented by the unit vector $\mathfrak{C} = 1 \times \varepsilon^{j\psi}$; the latter gives the angle through which the rotor winding has been revolved in relation to the stator winding in the direction of the rotating field. The ratio between the effective number of turns of the rotor winding and of the stator winding is indicated by the quantity U; it is the same for both induction regulators. If now, for the sake of simplicity, we neglect the light load currents of the induction regulators, we can write the fundamental equations of the induction regulators as follows:—

$$\frac{J_s}{U\mathfrak{C}} + J_r = 0 \; ; \quad \mathfrak{P}_1 - J_s\mathfrak{Z}_s + \mathfrak{E}_s - \mathfrak{P}_2 = 0 \; ; \quad \mathfrak{P}_2 + J_r\mathfrak{Z}_r - \mathfrak{E}_r = 0$$

$$\mathfrak{E}_s = \frac{\mathfrak{C}\,\mathfrak{E}_r}{U}$$; where $\mathfrak{E}_r$ and $\mathfrak{E}_s$ represent the EMF's induced in the rotor and stator windings, respectively, and $\mathfrak{Z}_r$ and $\mathfrak{Z}_s$ the leakage impedance of the corresponding windings. If we set the induction regulator (1) in the position $\mathfrak{C}_1 = \varepsilon^{j\psi_1}$ and the induction regulator (2) in the position $\mathfrak{C}_2 = \varepsilon^{j\psi_2}$, we can express the rotor currents J_{r_1} and J_{r_2} in the following manner:—

$$J_{r_1} \times \left[1 + \frac{\mathfrak{C}_2}{\mathfrak{C}_1} \times \frac{(1 - U\mathfrak{C}_1)}{(1 - U\mathfrak{C}_2)}\right] = J_2 \frac{\mathfrak{C}_2}{\mathfrak{C}_1 (1 - U\mathfrak{C}_2)} + \frac{\mathfrak{P}_2}{\mathfrak{Z}_{kr}} \times \left(\frac{\mathfrak{C}_2 - \mathfrak{C}_1}{\mathfrak{C}_1}\right)$$

$$J_{r_2} \times \left[1 + \frac{\mathfrak{C}_1}{\mathfrak{C}_2} \times \frac{(1 - U\mathfrak{C}_2)}{(1 - U\mathfrak{C}_1)}\right] = J_2 \frac{\mathfrak{C}_1}{\mathfrak{C}_2 (1 - U\mathfrak{C}_1)} - \frac{\mathfrak{P}_2}{\mathfrak{Z}_{kr}} \times \left(\frac{\mathfrak{C}_2 - \mathfrak{C}_1}{\mathfrak{C}_2}\right)$$

where $\mathfrak{Z}_{kr}$ represents the short-circuit impedance of the induction regulator at the rotor terminals, this quantity being

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made up of the components $\mathfrak{Z}r$ and $\mathfrak{Z}s$; $\mathfrak{Z}kr = \mathfrak{Z}r + U^2 \times \mathfrak{Z}s$. As the ratio U of the induction regulators is usually a high figure as compared with unity, the above equation can also be written as follows:—

$$Jr_1 = -\frac{J_2}{2U\mathfrak{E}_1} + \frac{\mathfrak{P}_2}{2\mathfrak{Z}kr}\left(\frac{\mathfrak{E}_2-\mathfrak{E}_1}{\mathfrak{E}_1}\right)$$

$$Jr_2 = -\frac{J_2}{2U\mathfrak{E}_2} - \frac{\mathfrak{P}_2}{2\mathfrak{Z}kr}\left(\frac{\mathfrak{E}_2-\mathfrak{E}_1}{\mathfrak{E}_2}\right)$$

$$(Jr_1 - Jr_2) = -\frac{J_2}{2U}\left(\frac{1}{\mathfrak{E}_1} - \frac{1}{\mathfrak{E}_2}\right) + \frac{\mathfrak{P}_2}{2\mathfrak{Z}kr}(\mathfrak{E}_2-\mathfrak{E}_1)\left(\frac{1}{\mathfrak{E}_1} + \frac{1}{\mathfrak{E}_2}\right)$$

As can be seen, the equalising current can be regarded as the geometrical sum of two members. The factors, depending upon the position can be expressed in a simpler way if we make use of the quantities: $\mathfrak{E}_1 = \varepsilon^{j\psi_1}$ and $\mathfrak{E}_2 = \varepsilon^{j\psi_2}$ and indicate the difference in angular displacement of the two induction regulators by the difference in angle:—

$$(\Psi_2 - \Psi_1) = \Delta\Psi$$

$$\left(\frac{\mathfrak{E}_2-\mathfrak{E}_1}{\mathfrak{E}_1\mathfrak{E}_2}\right) = j\,2\sin\left(\frac{\Delta\Psi}{2}\right) \times \varepsilon^{-j\left(\frac{\psi_1+\psi_2}{2}\right)} \cong j\Delta\Psi \times \varepsilon^{-j\left(\frac{\psi_1+\psi_2}{2}\right)}$$

$$\left(\frac{\mathfrak{E}_2-\mathfrak{E}_1}{\mathfrak{E}_1}\right) \times \left(\frac{\mathfrak{E}_2+\mathfrak{E}_1}{\mathfrak{E}_2}\right) = j\,2\sin\Delta\Psi \cong j\,2\times\Delta\Psi$$

In order to estimate the order of magnitude of these two members, we assume that the load J_2 is, in value, equal to twice the rated stator current of one induction regulator. We can then write:

$$\left|\frac{J_2}{2U}\,\frac{\mathfrak{E}_2-\mathfrak{E}_1}{\mathfrak{E}_1\mathfrak{E}_2}\right| = \frac{Jsn}{U}\Delta\Psi \text{ and}$$

$$\left|\frac{\mathfrak{P}_2}{2\mathfrak{Z}kr}\,\frac{\mathfrak{E}_2-\mathfrak{E}_1}{\mathfrak{E}_1} \times \frac{\mathfrak{E}_2+\mathfrak{E}_1}{\mathfrak{E}_2}\right| = \frac{Jsn}{2U}\,\frac{2\Delta\Psi}{\mathcal{E}ks} = \frac{Jsn}{U}\Delta\Psi\,\frac{1}{\mathcal{E}ks}$$

where $\mathcal{E}ks$ represents the percentage short-circuit pressure of the induction regulator at the stator terminals. As $\mathcal{E}ks$ amounts to about 18%, the second member in the equalising current is $\frac{1}{0.18} = 5$ to 6 times larger than the first member, and, consequently the value and phase displacement are fixed by the equalising current alone. We can, therefore, write:

$$(Jr_1 - Jr_2) = j\,\frac{\mathfrak{P}_2}{\mathfrak{Z}kr}\Delta\Psi$$

It is thus perpendicular to the vector $\left(\frac{\mathfrak{P}_2}{\mathfrak{Z}kr}\right)$ and independent, in its phase, of the position of the induction regulator, while it varies in value with the angular displacement.

Fig. 12 shows the position of the equalising current J_a, when the stabilising current transformer is in the phase R of the rotors. It can be seen, at the same time, that it is best to arrange the potential transformer of the automatic pressure regulator across the adjoining terminal pressure lagging behind it, i. e. across (R—S). A still better adaptation to the terminal pressure is obtainable by providing an inductive-ohmic resistance in parallel with the current transformers.

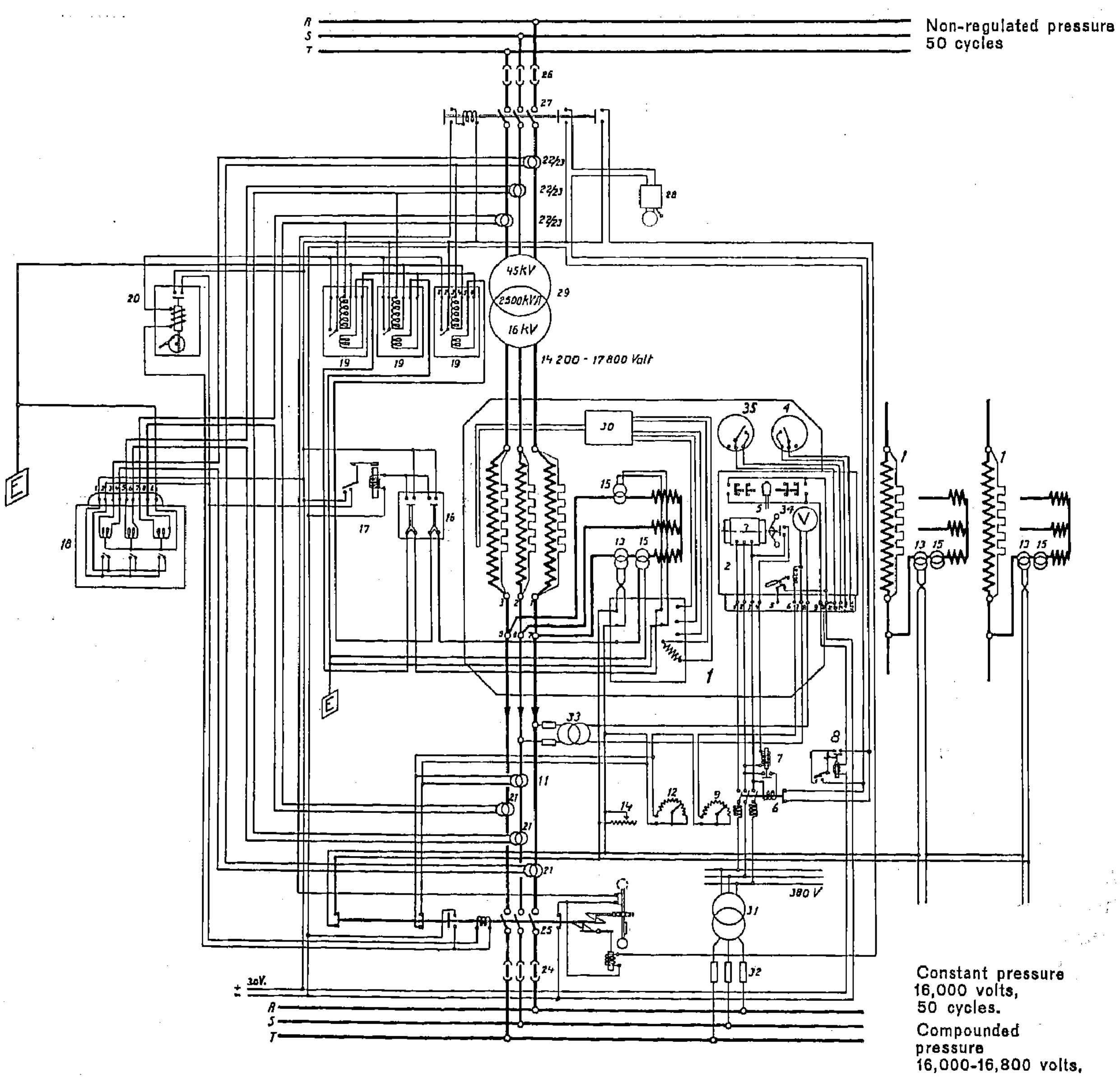


Fig. 13.

1 Induction regulator
2 Oil pressure quick-acting regulator
3 Induction motor
4 Contact pressure gauge
5 Signalling contact
6 Motor switch box
7 Protective relay
8 Relay for alarm circuit
9 Pressure adjusting resistance
10 Pressure relay
11 Current transformer for compounding
12 Adjusting resistance for compounding
13 Current transformer for stabilising
14 Adjusting resistance for stabilising
15 Current transformer
16 Thermo-relay
17 Auxiliary relay with shutter
18 Induction relay
19 Differential relay
20 Auxiliary time relay
21 Current transformer
22 Current transformer for indoor mounting
23 Current transformer for outdoor mounting
24 Isolating switch
25 Oil circuit breaker
26 Isolating switch
27 Oil circuit breaker
28 Alarm bell
29 Transformer
30 Temperature measuring device
31 Potential transformer
32 Potential transformer fuse
33 Potential transformer
34 Voltmeter 80—140 volts
35 Thermometer

If, as often suggested, the stator currents are used for stabilisation purposes, with this mode of connection, it will be found, by making a similar study, that the difference between the stator currents amounts to:—

$$(J_{s_2} - J_{s_1}) = -\frac{\mathfrak{P}_2}{\mathfrak{Z}_{kr}} U \times (\mathfrak{E}_2 - \mathfrak{E}_1)$$

This equalising current thus alters its phase with the position of the rotor of the induction regulator and is thus not suitable for stabilising purposes. Both the tests carried out and the good results obtained during many years of service have shown that the stabilising arrangement in question permits of the switching on and off of the individual sets working in parallel without flow of current, and ensures at all times the parallel operation of plant, even when the induction regulator is controlled by means of an oil pressure regulator, the distribution of the current between the individual sets being equalised automatically within 3—4 %.

Fig. 13 gives the diagram of connections of a substation with three induction regulators working in parallel. The induction regulators are operated by means of oil pressure quick-acting regulators. In this installation, provision is made,

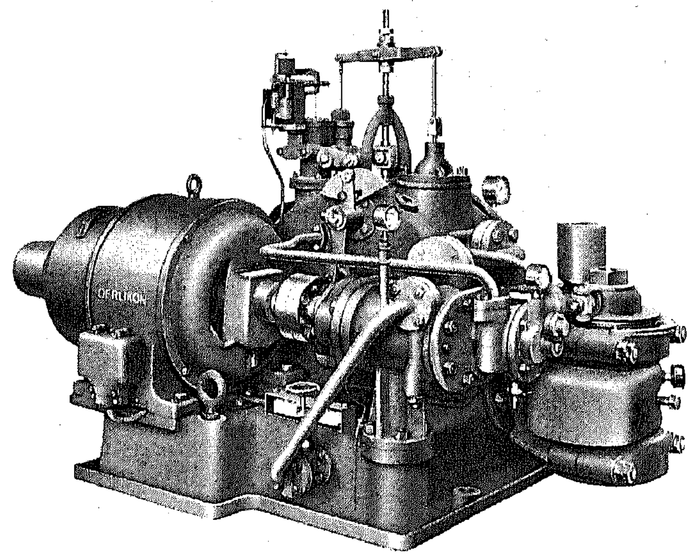


Fig. 14.

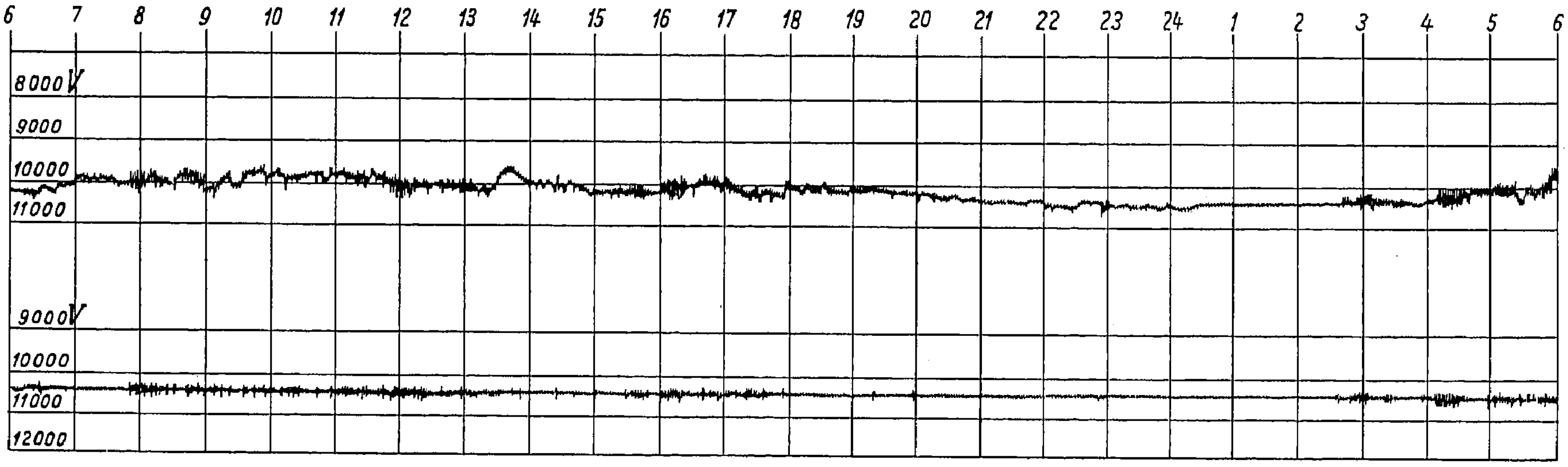


Fig. 15. Regulation obtained with an Oerlikon oil pressure quick-acting regulator for 3,000 ft.-lbs, on a 6,000 KVA, 3-phase double induction regulator. Above, non-regulated pressure (tramway, electric furnaces, power and lighting load), below, regulated pressure.

not only for the automatic regulation of pressure with compounding, but also for the stabilising of the parallel working of induction regulators in accordance with the method described for differential protection, and for the checking of temperatures at various points. A notable feature is that two of the induction regulators are for indoor mounting and the third for outdoor mounting.

The conditions laid down in practice with regard to the maintaining of a constant pressure have become very severe specially in distribution systems with a lighting load. It is a well-known fact that, when use is made of lamps with metallic filament, the variation of the intensity of light and the variation of pressure are in a ratio of 3.5 to 1. In order to ensure a satisfactory service, the total pressure variation should not exceed 2 %. The pressure is thus to be regulated in such a way that, at the supply point, the pressure is 2 % too high and at the end of the distribution system it is 2 % too low; this corresponds to a variation in the intensity of light of ±7 %. As long as the variation in pressure is slow, this value can still be regarded as permissible. If, however, such variations occur suddenly, they may, in certain cases, even be found unpleasant. All things taken into consideration, it can be said that, on the one hand, the supply pressure should be kept constant for the central portion of the distribution system and, on the other hand, that the distribution system should be calculated for a difference in pressure of ±2 % (see Burger, "Calculation of three-phase power transmission lines").

In most cases, the conditions are such that even the pressure at the feeding point is subjected to variations so that it is not a question of designing a supply circuit with negligible drop. The pressure regulating equipment must therefore work in conjunction with the supply in such a way as to ensure the necessary compounding for the compensation of the drop in the feeder or in the feeder and in the intermediate transformers, at the feeding point in the distribution system, the compounding effect of the pressure regulating equipment being such as to correspond to the drop, both as regards value and phase. To what extent this condition can be satisfied is a matter which has to be decided on the basis of economical considerations. In this connection, such factors as the cost of power transmission with

the economical section of conductor, the cost of the pressure regulating equipment, the amount represented by the losses in the transmission and in the pressure regulating equipment, have to be taken into account.

If technical considerations demand that the supply pressure should be maintained constant within the limits mentioned, it is also important for the supplier of power, for economical reasons, that this should be the case, as a certain increase in receipts may result for the Supply Company if the pressure is kept constant, which otherwise would be lost to them.

The requirements we have briefly outlined above, are satisfied in the fullest measure, by adopting pressure regulation by means of induction regulators. In every case, it will be necessary to arrange for the automatic operation of the induction regulators; it may be sufficient, according to the speed at which the regulation has to take place, to arrange for the control of the induction regulators by means of a contact voltmeter (for instance, a Thury regulator with carbon contacts) and a servo-motor, or an oil pressure quick-acting regulator may have to be resorted to for the purpose. In the former case, the induction regulator requires about 10—30 seconds to move from one end position to the other and in the latter case about 1.5 seconds. The sensitiveness of the pressure regulation amounts, in the case of both modes of control to about ± .5%.

In most cases, it is sufficient to provide for pressure regulation by means of a contact voltmeter and a servo-motor; Fig. 16 gives an illustration of an outdoor installation, for connecting directly to the system, designed on these lines. The external capacity of each transformer amounts to 6000 KVA at a pressure varying between 14,400 and 17,600 volts on the supply side and a pressure of 16,000 volts on the regulated side. The induction regulators are operated by means of 3-phase squirrel cage motors which are arranged in a separate casing, and actuate the induction regulators through the intermediary of gear wheels and shaft with slip coupling.

If we have to reckon with heavy current rushes as, for instance, when supplying power to steel works or rolling mills, it is necessary to make use of a quick-acting regulator. Fig. 14 shows an oil pressure quick-acting regulator, such as utilised for this purpose, for a nominal torque of 3000 ft.-lbs. The servo-motor is controlled by an electrically operated valve. The forced oil is supplied by a gear wheel pump, driven by an electric motor with automatic starter. Fig. 1 represents three induction regulators with built-on oil pressure quick-acting regulators; two of these are for indoor mounting and the third for outdoor mounting. In Fig. 15, we have reproduced a regulation strip of such an induction regulator equipment with oil pressure regulation. The upper curve shows the mode of variation of the non-regulated pressure and the lower one, that of the regulated pressure.

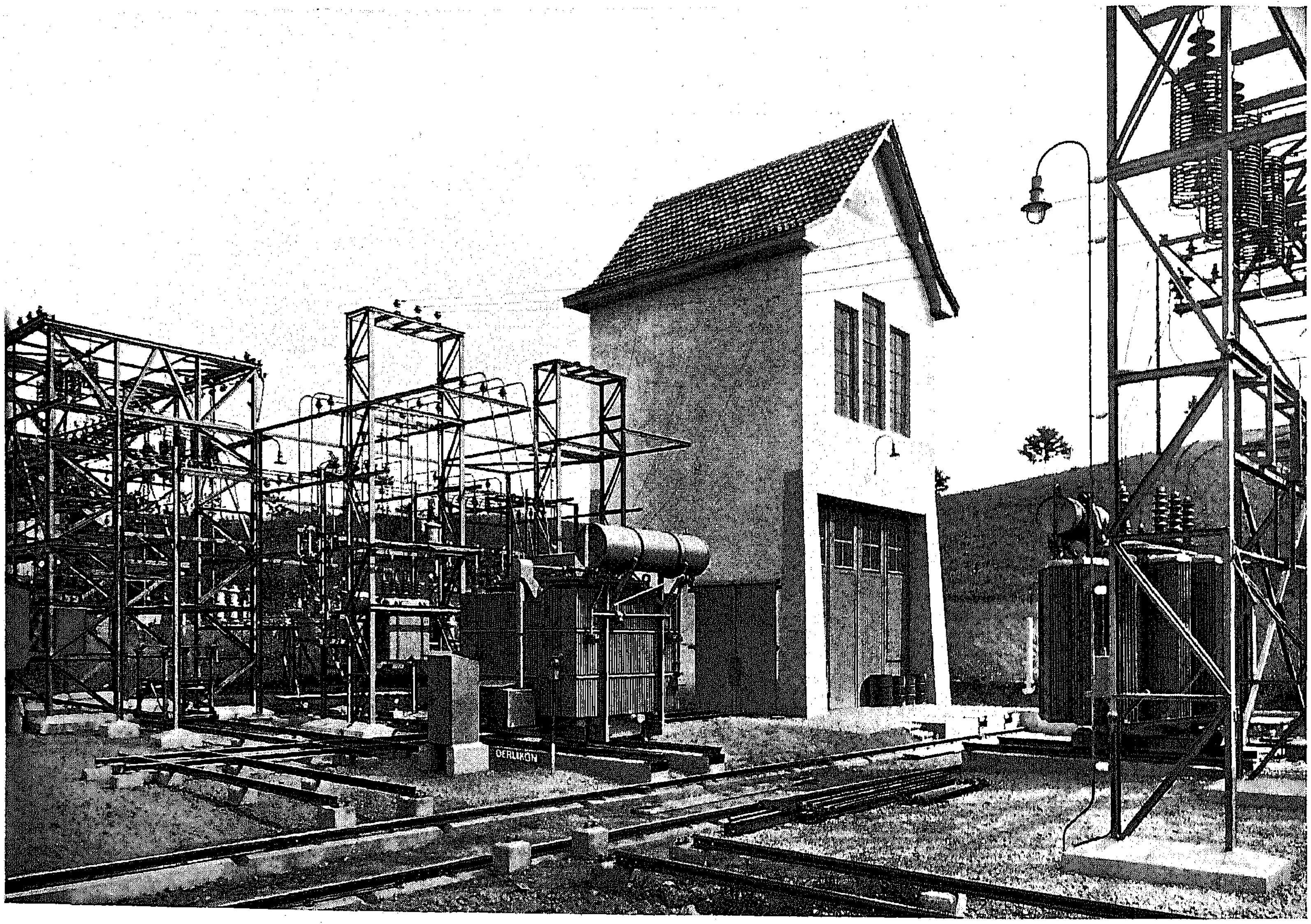


Fig. 16.

BULLETIN OERLIKON

No. 110 — August 1930

New Developments in Turbo-Generator Design.

Report to the World Power Conference, Berlin 1930, by Chief Engineer H. Rikli, Zurich.

The practice at the present day is to build steam turbines for larger and larger outputs at high speeds. In Europe, where 50 cycles is standard, the speed which is now given preference is 3000 RPM. These sets running at high speeds present special advantages as compared with 1500 RPM machines, both as regards mechanical safety of design (smaller dimensions in the case of high steam pressures) and as regards low manufacturing costs.

The magnitude of the developments which have taken place in this direction will be more easy to grasp if we mention the fact that, at the Electro-Technical Congress in Turin in 1911, the figure given as limit output for turbo-generators running at 3000 RPM, was 5700 KVA, that shortly before the war the limit reached was 7500 KVA, and that soon after the war, as a result of the possibility of manufacturing better kinds of steels for the rotors, outputs of 15,000—20,000 KVA where obtained, while, in recent years, turbo-generators at 3000 RPM have been built for 40,000 KVA; in fact, at the present time, single-unit turbo-generators for 50,000 KW or 72,000 KVA running at the same speed are in course of construction, as suggested by the Oerlikon Company. This last very large increase in the capacity of units has not been secured at the expense of mechanical safety or by further increasing the strength of material, but by using materials refined to the usual degree and by adopting for these materials a considerably higher safety factor than in the case of 30,000 to 40,000 KVA generators built up to now.

This apparent paradox has been achieved by using aluminium for the rotor winding, a mode of manufacture which has been resorted to by the Oerlikon Company for some 14 years, with the best results, in the case of turbo-generators for more than 10,000 KVA running at 3000 RPM.

When copper is used for the rotor windings, it is necessary, even for capacities from 20,000 KVA onwards, to make the rotor bodies of special highly refined alloyed steels, in order to ensure at least a theoretical factor of safety of 1.5 to 1.6 during the over-speed tests, before reaching the yield point.

These excessive requirements with regard to the quality of the rotor material have very probably been the cause of numerous explosions of rotors in the last years, as rotor bodies of such highly refined steel with yield points of 5500—6000 kg/cm^2 could easily contain flaws in the metal or anyhow could not be made entirely free from internal stresses so that, in addition to the very high stresses that come into play during service, there was still the wholly unknown quantity represented by the original stresses in the material, which actually rendered any factor of safety entirely illusory. On the other hand, it would seem, as a matter of principle, undesirable to go too far with the refining of steel with a view to attaining too high a tensile strength, as, otherwise, the permanent strength of the material is reduced out of all proportion. Through the adoption of aluminium for the rotor windings, this very difficult problem of ensuring mechanical safety has been satisfactorily solved. In the case of a 23,000 KVA generator at 3000 RPM supplied by the Oerlikon Company in 1926, to the City of Leicester, the values for stresses are, for instance, only 1400 kg/cm^2 for the maximum tangential stresses in the central bore of the rotor body and as low as 700 kg/cm^2 for the radial stresses in the rotor teeth. The factor of safety up to the yield point, which has a value of only 4500 kg/cm^2 is here still 2 to 4 at 25 % overspeed. The same figures apply to machines of the same size for outputs up to 37,500 KVA with correspondingly wider core, which have an actual width of core starting from 2500 mm.

Even in the case of the largest series of machines built by the Oerlikon Company, for 3000 RPM, which include generators for 65—90,000 KVA, the stresses in the rotor body are still relatively small, as compared with the figures which are to be found in the technical publications for outputs as low as 25,000 KVA.

These figures for the machines in question are as follows:

Radial stress at the base of teeth	= 980 kg/cm^2
Tangential stress at the base of teeth	= 440 kg/cm^2
Tangential stress in the central bore	= 1800 kg/cm^2

When the stresses have such values, it is still possible to use a steel only moderately refined with, for instance, a yield point with a maximum value of 4500 kg/cm^2; this steel is easier to manufacture and affords greater reliability, while there is, in any case, no danger of considerable internal stresses, as in the case of materials with a much higher yield point.

As a result of the use of aluminium for the windings of these high power generators running at 3000 RPM, the specific pressure in the insulating material has also been considerably reduced; in the case of such outputs as referred to they amount to 150 kg/cm^2 at the most. The conditions with regard to the end caps are also much sounder, as these caps can be built with much thinner walls than if the windings were of copper. In view of this, the caps are lighter and there is greater certainty of their being homogeneous. Furthermore, the maximum stresses at the inner periphery do not exceed the average stresses to such an extent as in the case of caps with thick walls.

Apart from the wisdom of limiting the stresses to relatively low values, so that it is still possible to use a rotor material which is homogeneous and free from internal stresses, the factor that actually provides the necessary guarantee as regards the safety of such generators built for limit outputs is, in very first place, a thorough and systematical testing of the rotor body.

ATELIERS DE CONSTRUCTION OERLIKON, OERLIKON

The Oerlikon Company have, for many years, proceeded on their own lines, in this connection, and have not only aimed at testing the safety of rotors after completion of plant, by subjecting them to undoubtedly severe over-speed tests, but they have also endeavoured to obtain data as regards the measure of this safety. The rotor can pass the prescribed over-speed tests without any apparent damage and yet be strained by the latter in its structure, so that it is no longer sound and may explode at the first opportunity when, for instance, the additional stress of sudden short-circuits is applied.

Tests carried out on discs taken from rotor bodies run up to such a speed as to cause their explosion have shown that it is possible to detect the danger of an explosion fairly early, owing to the rapid increase of the permanent expan-

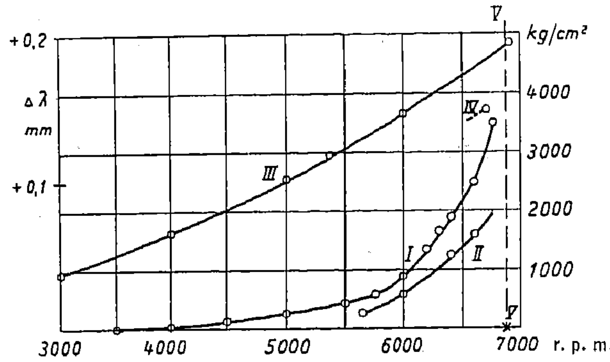


Fig. 1. Disc 708 mm in diameter.

I = Permanent increase in diameter between edges of poles.
II = Permanent increase in diameter along the neutral axis.
III = Peripheral stresses in the bore.
IV = Value for the second disc.
V = Exploded at 6900 r. p. m.

sion, as can be seen from the curves in Fig. 1. This has led to the devising of a testing method based on this phenomenon. The permanent expansion of the rotor body complete with slots, but without winding, is measured by means of a precision micrometer with an accuracy of $^1/_{1000}$ mm, specially built for the purpose, after successive over-speed tests at increasing speeds; the absence of the windings and of the wedges can be allowed for by increasing the speed, up to which the rotor is run, accordingly. If the curve arrived at by plotting the values obtained for the expansion up to the prescribed overspeed limit does not show a tendency to rise rapidly, the rotor body in question can be passed for further manufacture. It is, of course, necessary previous to this, to carry out a number of tests on the material itself and to inspect the bore with the greatest care, with a special instrument.

The question as to whether generators can be built for larger outputs than the figure of 90,000 KVA mentioned, at a speed of 3000 RPM is primarily governed by the necessity of keeping the stresses within permissible values; at the same time the length of the rotor is limited by the value of the critical speed. If the second critical speed is to be about 50 % above normal speed, the capacity of 90,000 KVA with stresses such as given above, represents the maximum that can be attained at 3000 RPM.

The exceptional advantages derived from the use of aluminium for the rotor windings are, it is true, counter-balanced by an increase in excitation power required, as the conductivity of aluminium is only about 60 % of that of copper. In view of this, the losses of the rotor to be led away by the cooling air are, all other conditions being equal, higher to that extent. In the case of these modern turbo-generators, about 10,000—12,000 amp-conductors are accommodated on the rotor per slot and about 180,000 amp-turns per pair of poles, which means losses amounting to about 600—700 watts/cm length of rotor body. Such losses cannot be dissipated through the rotor surface alone. It is, therefore, necessary to resort to a very ample internal ventilation of the whole rotor winding, while the provisions for the cooling of the ends of coils and of the winding in the slots must be such as to ensure, as far as possible, an even distribution of temperature along the whole winding. In view of the fact that thin layers of air reduce considerably the conduction of heat, it is most important to see that the winding fits very tightly in the insulated slots so that a good dissipation of heat should be obtained. Furthermore the ends of windings are to be so subdivided, and the provisions for the access of cooling air are to be such, as to prevent any accumulation of heat.

The following figures will give an idea of the very ample way in which the rotor has to be designed with regard to cooling. The rotor of the 25,000 KVA generator at 3000 RPM previously referred to, had to dissipate through a total cylindrical surface of 7.3 m², a quantity of excitation power amounting to about 100 KW, or more than 13 KW/m² with a normal temperature rise of 75° C. The aluminium strip used for the rotor winding was then carrying a current of 4 amps per mm².

Although the question of mechanical safety of the rotor body is one that relegates all other considerations to the background, the Oerlikon Company have, of course also given very careful attention, when designing the plant, to the other points affecting its operation. Foremost among these is the problem of rendering the machines capable of withstanding short-circuit stresses and that of reducing the additional losses and the losses in general to the lowest value.

The principal difficulty, when designing supports for the ends of coils, capable of withstanding short-circuit stresses, is to ensure that the cooling of the winding is not impaired, while, at the same time, the design of the supports is rendered somewhat complicated, owing to the fact that the copper sections in the ends of coils have to be sub-divided according to certain rules, as will be shown later on, in order to avoid excessive additional losses in the ends of coils. It can be said that the design evolved by the Oerlikon Company is thoroughly satisfactory in this respect. The efficacity of the mode of support in question has been tested on a trial generator, specially built for testing out this design, the machine being subjected to over 500 short-circuits; in addition to this, all large generators supplied also undergo trials with sudden short-circuits, with a view to testing their ability to withstand short-circuit stresses, even when no further conditions than the ordinary provisions are stipulated in the order.

The stator windings of the large Oerlikon turbo-generators are always of the lattice type; they are arranged in two tiers and, as is generally the case in Europe, these tiers are parallel to the press plates, an arrangement which permits of the very secure fastening of the ends of coils to the press plates. The design has further the advantage that the supports can be made, in greater part, of slabs of insulating material, a factor which has a favourable influence on the value of certain additional losses. The winding in the two tiers is rigidly held in position, along the periphery, at the point where it emerges from the slots, by means of combs,

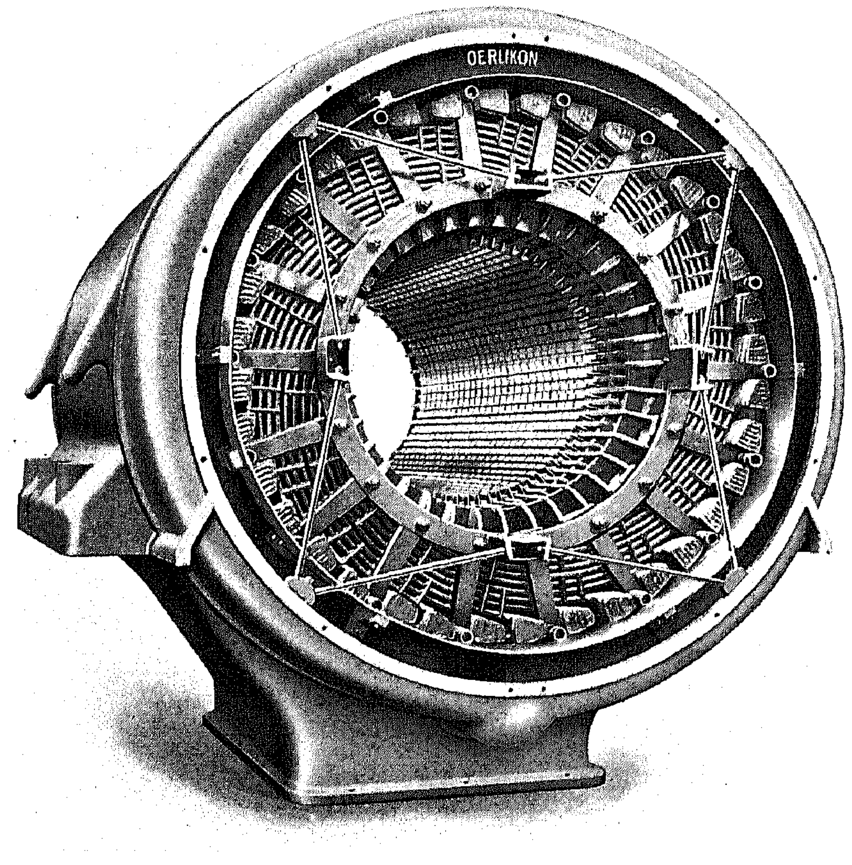


Fig. 2.

in the customary way. The maximum stresses, in the case of one-sided single-phase short-circuits, across two phases, would amount to about 80 kg per cm length in the case of the conductor situated in the most unfavourable position, and can be dealt with by providing two combs 15 to 18 cm. apart, in an axial direction. The forces are, however, greatest in the ends of coils, between the conductors of the same phase, in the same tier and, while the distances are small between the individual coils, the amplitude of the first wave can assume a value as high as 1,000,000 amp-conductors, per pole and phase, in the case of a sudden one-sided short-circuit. These stresses which, when the conditions are unfavourable, can assume a value of 100 kg per cm length of coil, are taken by numerous intermediate supports which should be not more than 8 to 10 cm apart owing to the subdivision of conductors required, in order to reduce the additional losses. The ends of coils are anchored at a certain number of points, at the outer periphery, to the projecting parts of the casing and made secure, as a whole, against any angular displacement, by arranging that all the stresses occuring in the ends of coils, in the case of a short-circuit, should have their own reaction point against which they are directly applied. Fig. 2 gives a general view of an arrangement for supporting the windings, such as used at the present day by the Oerlikon Company.

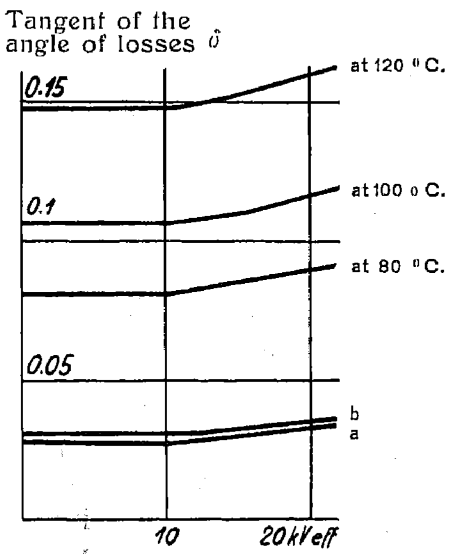


Fig. 3. Pressure corresponding to losses in turbo-generator coils.
a = In the condition as supplied.
b = Cooled down after heating up to 120° C.

Another point to be mentioned, when considering the question of safety, is the strength of the insulation. The insulation tests prescribed by the R. E. M. 1930*) and by the I. E. C.**) including the tests dealing with surges, cannot be taken into consideration as they are in fact of a fairly harmless nature (at least in the case of machines up to a maximum normal pressure of 10—15,000 volts). Severe insulation tests have, however, been prescribed by certain clients, which tests have been accepted by manufacturing firms including the Oerlikon Company, and it is quite probable that these more severe conditions will be generally adopted and resorted to more frequently.

In order to test the homogeneity of the insulation of coils, that is to say of the micanite sheath which is pressed on the portions of the coils situated in the slots, the stipulation is made that the so-called ionisation "deflection" is to be above the pressure to which the insulation is permanently subjected during service; in other words, the curve giving the tangent δ (angle of losses) in function of the applied test pressure is, as far as possible, only to show a noticeable deflection above that pressure, both in the case of the tests carried out on the machine on delivery and after it has been heated to the maximum temperature encountered in service. Furthermore, the angle of losses is to be very small, even below this point, and the tangent δ is not to amount to more than about 0.05. Both these points afford a criterion as to the compactness and homogeneity of the insulation, while they also indicate that the latter is free from small air spaces, as far as this is possible, and that the binding medium has good dielectric properties. Fig. 3 gives the results of such tests carried out on a stator coil.

A further test of a severe nature is that where the insulation of coils is subjected, for a prolonged period, to a pressure equal to a multiple of the working pressure. Stipulations are made that a pressure amounting to 4 to 5 times the working pressure is to be applied for 10 hours, without this resulting in a breakdown or flash-over. This test is intended to deal with the case of excess pressure during service and to furnish a guarantee that the insulation of the machines can withstand such conditions without damage, even in the event of their occurring frequently. Whether these tests are actually justified or are merely rendering the machine more costly, is still problematical. It has, however, been actually possible to satisfy these conditions even up to working pressures of 10,000—11,000 volts, though this has meant an increase of material required and of labour, in no way inconsiderable for the manufacture of this insulation.

In order to obtain a good distribution of the electric field, specially at the points where the coils emerge from the slots, it is of advantage to embody in the material surrounding the coils, thin layers of metal foil, stepped in relation to each other. At the same time, it is a useful precaution to give the outer surface of the coils a thin semi-conductive coating, which prevents the occurrence of corona effect.

There is yet a further point which is of considerable importance, when designing large turbc-generators, namely,

*) R. E. M. = Rules for the rating and testing of electric machines, of the Association of German Electrical Engineers.

**) I. E. C. = International Electro-Technical Commission.

the reduction of the losses and more especially the limitation of the so-called additional losses to the lowest possible value. Quite apart from the fact that the task of arranging for the dissipation of the enormous amount of heat, due to the losses, by the cooling medium, represents a problem which is not easy to solve, there is another question which is of great importance, namely that of ensuring a high efficiency for the turbo-generator, as this means a reduced steam and coal consumption; this can be an important consideration from a financial point of view, specially in the case of large units, even when the amount in percent is small. It can be roughly estimated that the saving in coal per year corresponding to a 1 % reduction in steam consumption or, what is equivalent, to a 1 % increase in efficiency of generator, represents a sum in shillings of which the numerical value is equal to 40 % of the number of KW's developed by the set in question. If this amount were capitalised, quite a considerable figure would be arrived at, even in the case of an improvement in efficiency of a few tenths of percents.

The losses that form the greater part of the additional losses referred to above are those due to the load-current. The so-called primary portion of these losses, that is to say, the part which has its seat in the stator copper itself is, according to the papers of Field, Rogowski and others, easily and accurately ascertainable, and can be kept within permissible limits, even in the event of large currents per slot. It must, however, be said that certain portions of the additional losses, in the copper itself, are very much underestimated, namely, the additional losses in the copper of the ends of coils. Large generators which have, as a rule, only one conductor per slot are, in fact, very often designed with the slot conductors split up into layers which are twisted over according to one of the well-known methods, while solid copper conductors are used for the front connections, the latter being bolted to the slot conductors and soldered. Exhaustive tests with a view to determining the local losses, have shown that it is just at these connecting points and in the solid front connections that a great part of the additional losses in the copper itself occur, these having been overlooked owing to the fact that the cooling is usually very good there. These additional losses can, in the case of large sections, easily amount at these points to three to four times the value of the ohmic losses. In view of this, the arrangement in question is only used for relatively small ratings of 1000 to 1500 amp-conductors per slot. In the case of larger ratings, the Oerlikon Company utilise another arrangement where the sub-division of the slot conductors is continued in the ends of coils, the place where the cyclic permutation of the different layers takes place or where the conductors are crossed, being shifted to the points of connection, at the outer periphery of the ends of coils — a method they have resorted to for many years. Furthermore, a special arrangement of the conductors in the ends of coils permits, at the same time, of the reduction of the additional losses in the latter, to quite a small value. While, with the ordinary arrangement, even relatively small conductors, only 10 mm wide, may have an average loss ratio of 1.5 to 1.6 in the ends of coils, it is possible by disposing the conductors with their wide side in the main direction of the stray field, to obtain a value of 1.05 to 1.1.

Fig. 4 shows the effect of the above measures in the case of a 30,000 KVA turbo-generator at 3000 RPM. The curves a and b give the loss ratio over the whole length of a half coil, for a normal position of conductor and for the corrected position of conductor, while the curves c and d represent the respective temperatures rises. The saving secured amounts, in this case, to about 20 KW in the matter of additional losses alone, in spite of the fact that the conductors are only 10 mm wide. A far greater gain, in percent, is, however, obtainable, even in the case of widths of conductors of 12 to 14 mm.

The main portion of the additional losses is, however, represented by the so-called secondary additional losses, which occur in the press-plates, in the parts of casing, in the supporting structure and at the surface of the rotor.

It is not possible to determine directly their value, but there are certain ways in which these losses can be appreciably reduced. In first place, use can be made of non-magnetic end caps in the case of large units, a measure which leads to a considerable reduction of these losses. The substitution of cast-iron in the case of the covers and press-plates by a non-magnetic material has a similar effect; the latter must, however, have a good electrical conductivity or

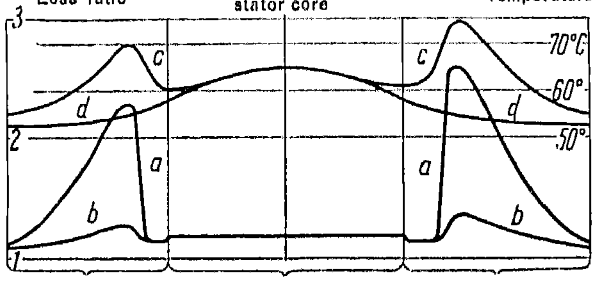


Fig. 4. Temperature rise and loss ratio in turbo-generator coils.

the steel press-plates of the core must be provided with copper damping plates, in order to afford a low resistance to the secondary currents.

On the other hand, it is possible by suitably reducing the pitch in the case of the stator winding, to restrict, to a considerable extent, the amplitude of the sixth harmonic, which is due to the residual field of the stator winding and, consequently, to limit the losses at the surface of rotor. The adoption of a small ratio between the pitch of slots and the radial air space has also a very favourable influence in this respect. As a result of all these partial and local improvements, the sum of the losses due to the load-current have been reduced in the case of large modern turbo-generators to less than 1 % of the KVA capacity, in spite of the fact that the current density per cm circumference may amount to even more than 700 amp-conductors, as is the case for our large units.

It is to a great extent, through the systematic measuring of the local losses, that this success in dealing with the additional losses has been achieved by the Oerlikon Company. For this purpose, use has been made, with advantage, of the method based on the initial temperature rise. When the specific heat of a body is known, it is possible to derive, by means of well-known laws, from the tangent to the curve representing the temperature rise caused by a loss process in that body, the losses which have taken place per unit of volume or weight; this can be done easily by using thermo-couples. The specific heat of a given part of a ma-

chine can be determined, in certain cases, by direct measurement as, for instance, in the core, while in the windings this quantity can be ascertained by means of similar tests with direct current.

It is important, with all these tests, to determine exactly and rapidly the time and the corresponding rise in temperature during the first 30 to 40 seconds after switching on the current or applying the magnetisation. Such measurements of losses, by means of the temperature rise are, at the present time, made at the Oerlikon Works in the case of all large units. All these improvements have also led to a reduction of the quantity of cooling air required. As the ventilation losses represent, in fact, in the case of large units, always the largest portion of the total losses, it is easy to see what a saving can be secured in this way.

Other losses which form a fairly large fraction of the total losses are, in the case of large high-speed turbo-sets, the magnetisation losses, which it is endeavoured to reduce by using highly alloyed stampings. With the enormous flux per pole in these machines, there is, however, always a great danger of eddy currents, specially between stampings which may be in contact; this phenomenon which is called "iron-disease" has often resulted in very serious damage to the insulation of the slots and in short-circuits between phases of the stator winding and to earth, owing to the local heating, to which it gives rise and which, of course, mainly occurs in the bore and at the upper surface of slots. It is, therefore, a matter of great importance to remove entirely this source of losses, the best way being to file off any burrs that may be due to the stamping of laminations, and by insulating carefully the laminations themselves. It is easy to test the core in a reliable way with regard to the presence of any such dangerous short-circuit paths, by resorting to ring magnetisation and faulty parts can then be removed before inserting the winding.

The most suitable type of slot is the open slot, as it is never possible, in the case of large widths of core, to ensure a good fit of the conductors in the slots, when the former are driven axially, with the result that, apart from the defective heat dissipation to which this gives rise, the bars are very liable to oscillate and can thus damage the insulation. In order to prevent the main field from penetrating into the slot conductors, and thus producing high losses in the latter, the saturation of the teeth has to be kept moderate. On the other hand, it is possible to adopt, with advantage, an arrangement where the depth of the slots is such as to leave a certain height clear, at the top; in this way, an energetic cooling of the projecting teeth is at the same time ensured and the dissipation of heat from the parts of the machine, where the heating is greatest, is considerably improved.

Owing to the fact that the windage losses represent a large proportion of the total losses, attempts have been made, from time to time, to arrange for the use of other cooling mediums. It was already suggested, many years back, to use oil for cooling the stator, the latter being closed off from the rotor by means of an insulating cylinder and filled with oil, cooled through the intermediary of a circulation system. In this way, the difficulties encountered in the case of high working pressure were, at the same time, removed to a considerable extent. Again of late patents, which are quite unjustified, have been taken out for such a design. The difficulty of making the joints perfectly tight and the unpleasant, complicated and lengthy work entailed in the case of overhauling, or when carrying out repairs on the stator winding, which must still be necessary, in spite of the protection afforded by the oil, render this design, attractive as it may appear, hardly practical.

The same applies to the substitution of air by another gas, hydrogen, in particular. The fact that this gas is exceptionally well suited for use as cooling medium may render such a suggestion attractive, as amongst other advantages it would mean practically the elimination of the largest loss item — that of the windage losses — the task of making the joints perfectly tight to atmosphere is so awkward and difficult that this interesting solution can only be regarded as economical in the case of synchronous condensers which can always run in an air-tight casing.

The continual improvements made in the various details of design which have all been directed at reducing the losses in the machines have made their influence felt still further. As a result of these improvements, it has been possible to reduce more and more precisely the loss items with the largest value, namely, the windage losses. The extent to which the goal aimed at has been approached is best shown by the values of efficiencies which can be guaranteed and obtained with large turbo-generators at the present time. Efficiencies as high as 97.5% at power factor unity have been measured at the Oerlikon Works on standard 20,000 and 25,000 KW. turbo-generators at 3000 RPM and, in the case of larger units, values of 97.8 to 98% will be most surely attained.

Measuring Devices for the Recording of Impact Pressures of a Rapid Nature.

1) Available measuring methods. There are, at the present day, many methods available for measuring and recording static pressures or pressures of a slow nature. When, however, it is the case of recording pressures of a rapid nature, it is not possible to find any satisfactory method of measurement.

For a long time, it was necessary to be content with Brinell's ball pressure meter. The design of this apparatus can be seen from Fig. 1. The value of the pressure acting on the piston can be deduced from the size of the imprint of the steel ball on the lead plate. The drawback of this measuring apparatus consists in the fact that it is only possible to measure the maximum pressure during the impact. It is, furthermore, questionable whether a given pressure acting during a very short time leaves the same size imprint on the lead plate as when the impact is of some duration. Measuring gear was subsequently built, where use was made of the property of certain materials, such as granulated carbon, carbon discs or metallic spheres, of varying

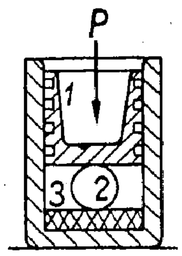


Fig. 1.
1 Piston
2 Steel ball
3 Lead plate

their resistance to the passage of current, according to the pressure to which they are subjected.

All these measuring methods present the serious drawback that the resistance to the passage of current varies, for the same pressure conditions, in the case of readings taken at different times, and that the value of resistance alters after each pressure measurement.

Another type of measuring apparatus is that where the pressure acts, through the intermediary of a pressure gauge tube or a diaphragm, upon a resistance wire or segments of a contact path in such a way as to cause variations in current, the latter being recorded by oscillographs. This gear is, however, easily affected by vibrations and outer influences such as dust and moisture.

Another method resorted to of late is based on the property of certain special materials of altering their internal resistance as a result of pressure; these materials appear, however, not to be sufficiently free from inertia, so that a disturbing reaction is introduced.

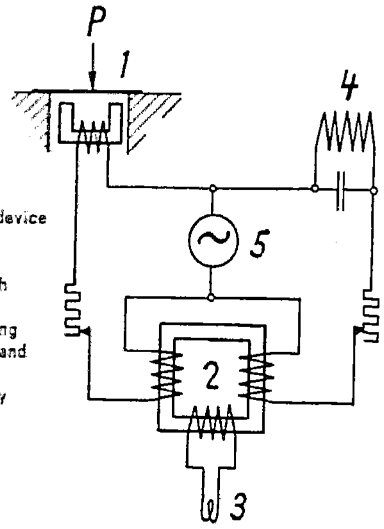
very high. In view of this, the Oerlikon Company have evolved a pressure measuring device with piezo-electric quartz crystal, which no longer presents the drawbacks in question.

1) Pressure measuring device with piezo-electric quartz crystal.

The piezo-electric effect of quartz and turmaline crystals is a phenomenon which has been known for a long time. It is the property of these crystals to liberate a certain quantity of electricity when a pressure is exerted on them. According to the measurements of Curie and Cady, this quantity varies precisely in the same ratio as the pressure. If we provide a metallic coating on two surfaces of a prism-shaped crystal, facing each other, a quantity of electricity is liberated when a pressure is applied on the crystals, such as causes one of these metal coatings to be charged always negatively and the other always positively.

In order to be able to plot the pressure in function of the time, the variable quantity of electricity produced by the pressure must be amplified by means of valves. The ampli-

Fig. 2.



1 Pressure measuring device
2 Differential transformer
3 Oscillograph loop
4 Compensating inductance and capacity
5 A. C. supply

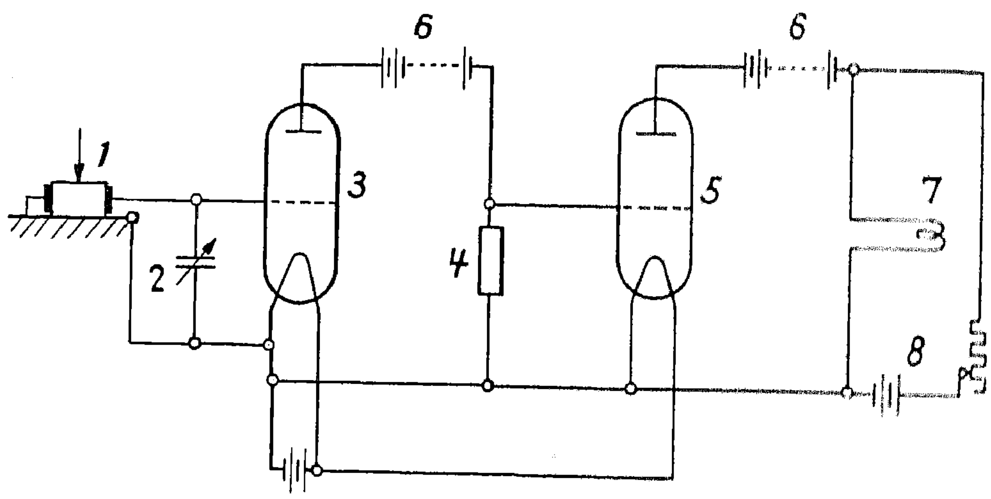


Fig. 3.

1 Quartz crystal
2 Variable condenser
3 First amplifying valve
4 Resistance
5 Second amplifying valve
6 Anode battery
7 Oscillograph loop
8 Compensation of the steady current of the valve

More recent tests have been carried out on other lines; they have aimed at converting the variations in pressure into variations in capacity or inductance. This result can be attained by designing the measuring device in the form of a small condenser or a solenoid. The movement of the diaphragm then causes an alteration in the capacity or the inductance. Fig. 2 shows the arrangement in question. When the pressure exerted is zero, the two currents of the differential transformer are balanced, by means of the compensating inductance or capacity, in such a way that the current in the loop of the oscillograph is zero. Every variation in pressure in the measuring device then causes a corresponding current to flow through the oscillograph. The mode of variation of the pressure is given by the enveloping curve of the impressed alternating current. It is, however, not possible even by using frequencies of a few hundred cycles to record perfectly pressures of a very rapid nature.

A means by which this drawback can be overcome was first found by H. A. Thomas; he used a valve in a high frequency modulation circuit. The frequency of the high frequency A. C. was about 800,000 cycles [1]).

All the measuring devices we have described have the great drawback that the natural frequency of oscillation is not

[1]) H. A. Thomas: "Precision measuring instrument for small motion of solid bodies" in "The Engineer" of the 9th Feb. 1923, Vol. 135, page 138, and "The measurement of mechanical vibration" in "The Engineer" of the 23rd Jan. 1925, Vol. 139, page 102.

fying arrangement is shown in Fig. 3. A variable condenser 2 is arranged in parallel with the two metallic coatings of the crystal. The negative plates of this condenser are connected to the grid of the first valve. The electricity produced by the pressure charges the condenser 2; consequently, the grid is subjected to a certain negative tension in relation to the filament. If we designate by dQ the quantity of electricity produced by the pressure dP, we can write: —

$$dP = k \times dQ \quad \text{or} \quad dP = k \times c \times dE,$$

where k = constant, c = capacity of the variable condenser and of the wires, E = pressure at the condenser. This means that the pressure varies in the same ratio as the tension at the condenser, if the value of capacity c is constant. On the other hand, if the amplifying valves work in the straight portion of their characteristic curve, the deflection of the oscillograph is directly proportional to the pressure. The whole amplifying gear is arranged in a small box. The variable condenser can be adjusted by means of a graduated disc; in this way, regulation facilities are provided for measuring pressures of different magnitudes. In the case of the apparatus in question, the deflection of the measuring loop can, for instance, be varied, for the same pressure, in the ratio of 1:12. The insulation between grid and filament of the first amplifying valve plays a very important part. In fact, if the value of this insulation is too small, the electricity to be measured is discharged at once, so that this

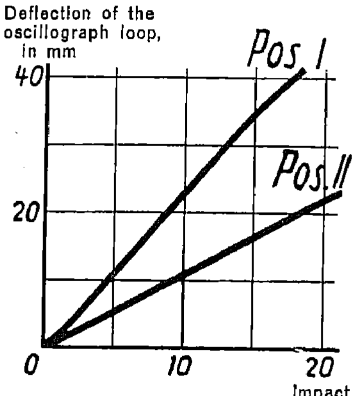


Fig. 4.

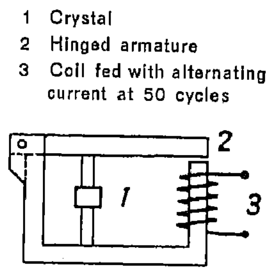


Fig. 5.

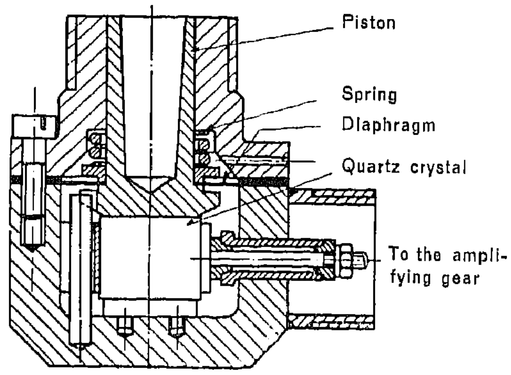


Fig. 8.

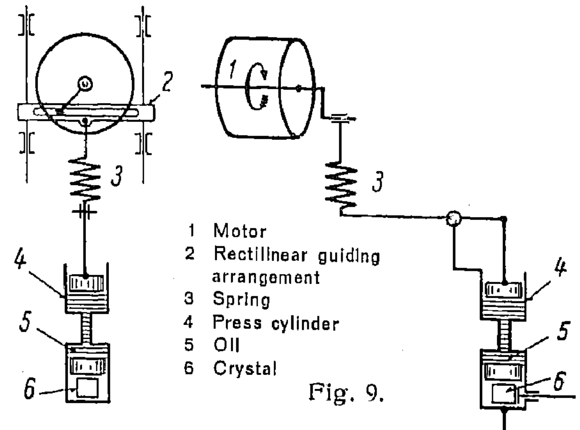


Fig. 9.

prevents the measurement of pressure impacts of a slow nature. The insulation of the valve used is such that the time constant of discharge is about 7 to 40 seconds, according to the position of the variable condenser, that is to say, a charge communicated to the condenser decreases from 100 to 37% in 7 and 40 secs., respectively. As the measuring apparatus is built for pressure impacts with a duration of less than 1 second, the discharge in question is practically of no importance. Fig. 4 gives the deflection of the measuring loop of the oscillograph in function of the pressure exerted on the crystal for two different positions of the variable condenser. The results obtained confirm the fact that there is a linear relation between deflection and pressure.

3) Results of tests. In order to obtain data with regard to the correct operation of the new measuring apparatus for pressure impacts, a number of tests were carried out; these will be briefly described below. The crystal used was arranged between the hinged armature of an electro-magnet and the frame of the latter (Fig. 5). The coil of the electro-magnet was fed with alternating current with a frequency of 50 cycles. As the force exerted on the armature is approximately proportional to the square of the current, it varies in time according to the following equation:

$$K = k \times J^2_{max} \times \sin^2 \omega t = k \times J^2_{max} \left[\frac{1 - \cos 2\omega t}{2}\right]$$

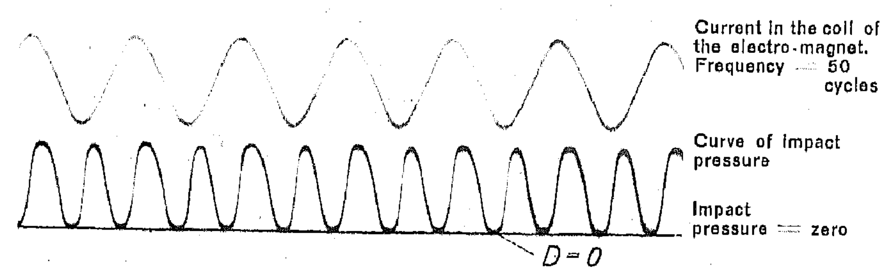


Fig. 6. Force exerted on the armature of an electro-magnet.

where J_{max} = amplitude of the current. This equation represents a curve with twice the frequency of the current with which the coil is energised. In Fig. 6, we have reproduced a curve of this description corresponding to the measured values of forces. Measured and calculated values agree well.

In order to have a curve for a more rapid impact, a blow was given to the crystal with a steel hammer; the oscillogram obtained is given in Fig. 7. The duration of the impact was about $^{18}/_{10000}$ of a second.

In order to be able to record the mode of variation of the pressure in fluids or gases, special measuring devices have been evolved; one of these is shown in Fig. 8. The medium used for transmitting the pressure is a diaphragm or a small piston according to the purpose. It may further be mentioned that in the case of oil, this transmitting medium can be dispensed with entirely. The oil then acts directly upon the crystal.

As the modulus of elasticity of quartz is about 0.8×10^6 kg/cm², the pressure measuring apparatus in question presents, in very first place, this great advantage that the movement of the pressure transmitting medium is practically zero, even in the case of great impact pressures, that is to say, that the natural frequency of oscillation is very high.

In order to test the accuracy of the pressure measuring equipments built, the apparatus was subjected to the action of a spring which was extended and distended by means of an electric motor, in such a way as to cause it to exert a force varying according to a sinusoidal curve. The force was transmitted to the pressure measuring apparatus by means of a piston. The arrangement adopted for the tests is shown in Fig. 9. The oil pressure measured with the measuring apparatus agrees with the measured force of the spring.

On the occasion of explosion tests carried out on the explosion chambers of oil circuit breakers, the measuring apparatus was used for determining the pressure of the explosion. The maximum pressure derived from the value of

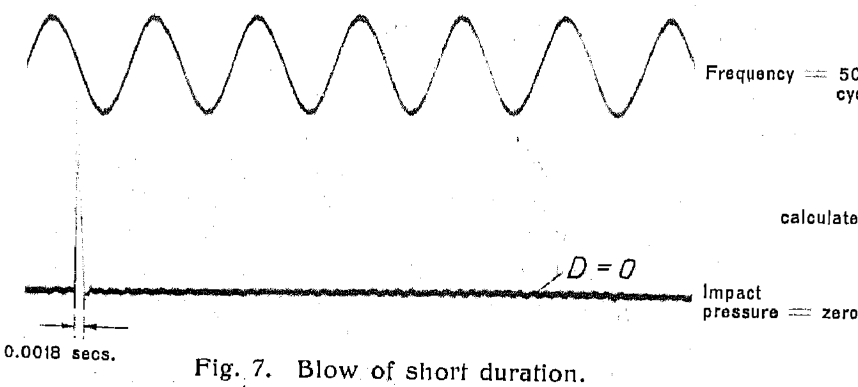


Fig. 7. Blow of short duration.

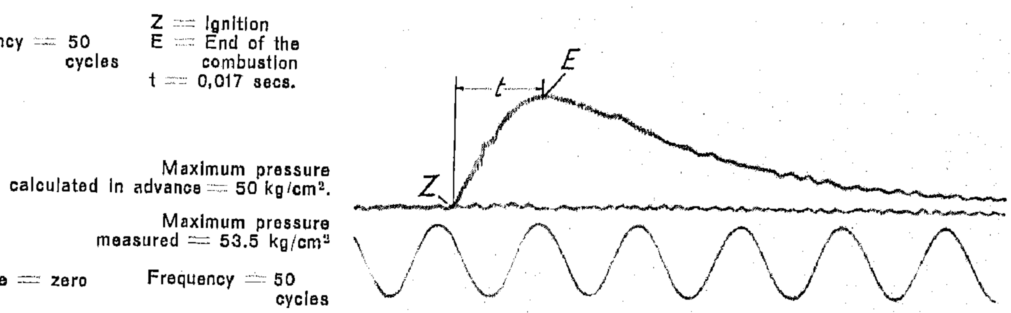


Fig. 10. Explosion tests in explosion chambers.

the sudden charge did not differ, at any test, from the measured maximum pressure by more than 8%. Fig. 10 shows the mode of variation of such an explosion pressure. The calculated maximum pressure amounted to 50 atmospheres, the measured pressure to 53.5 atmospheres.

We may further refer here to two other applications of this type of measuring apparatus. If we connect in parallel with the quartz crystal a resistance with not a too high ohmic value, in place of a variable condenser, any quantity of electricity liberated is discharged through the resistance. If we choose the value of resistance in such a way that the time constant, which is given by the expression $T = R \times C$, is very much smaller than the time of oscillation of the oscillations communicated, it is possible, with this apparatus, to record the variations of the force in function of the time $= \frac{\Delta P}{\Delta t}$.

The measuring device evolved can also be used for plotting power curves with an ordinary Siemens loop oscillograph, the arrangement in question being the object of an application for a patent. The mode of connection in question is represented in Fig. 11. The two plungers a and b are separated from each other magnetically, but coupled mechanically, by means of the connecting member, d. The plunger of the magnet system I exerts a force K_I in a downward direction and the plunger of the magnet system II a force K_{II} in an upward direction. The difference $K_I - K_{II}$ acts on the crystal.

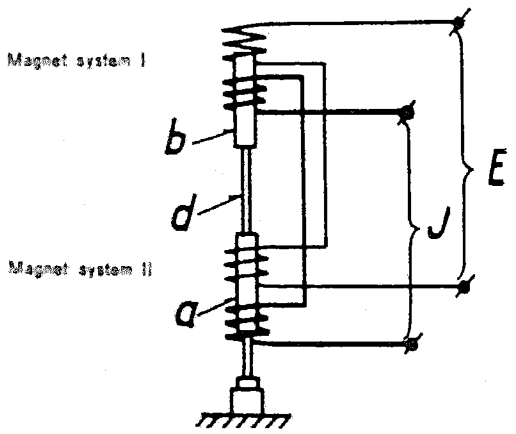
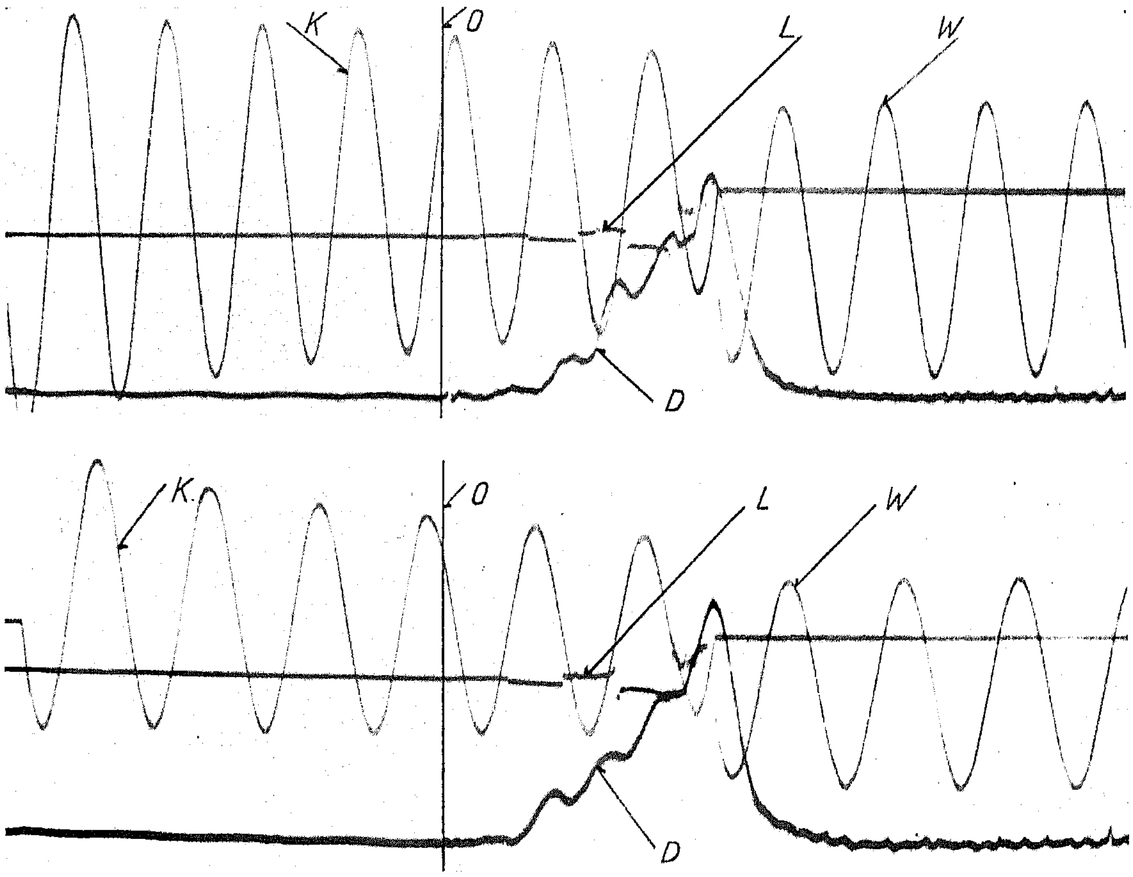


Fig. 11.



K = Short-circuit current
O = Opening of the contacts
L = Arc pressure
W = Recurring pressure
D = Impact pressure

Fig. 12.

In the magnet system I, the current and pressure coil are connected in such a way that the two magnetic fluxes are in phase, at power factor unity. In the magnet system II, however, they are at an angle of 180°. The force acting on a plunger is proportional to the square of the resulting flux. We thus have in every moment:—

$$\Phi_I = k_1 e + k_2 i \qquad \Phi_{II} = k_1 e - k_2 i$$

$$K_I = k_3 \Phi_I^2 = k_3 \left(k_1 e + k_2 i\right)^2 = k_3 \left(k_1^2 e^2 + 2 k_1 k_2 e \times i + k_2^2 i^2\right)$$

$$K_{II} = k_3 \Phi_{II}^2 = k_3 \left(k_1 e - k_2 i\right)^2 = k_3 \left(k_1^2 e^2 - 2 k_1 k_2 e \times i + k_2^2 i^2\right)$$

$$K_I - K_{II} = 4\, k_1 k_2 k_3 \times e \times i$$

The tests carried out have given very satisfactory results. The measuring apparatus in question was specially built for investigating the pressure conditions in explosion chambers of large oil circuit breakers, as well as for determining the relation between the switching work and the pressure developed in the explosion chamber. In Fig. 12, we have reproduced two curves showing the mode of variation of the pressure in the explosion chamber of an oil circuit breaker during a switching off operation, with A. C. at 50 cycles.

The whole pressure measurement is simpler still when curves are taken by means of the cathode ray oscillograph[2]. The two metallic coatings of the crystal are connected directly to the two diverting plates of the oscillograph. The whole amplifying arrangement can thus be dispensed with. Even if it were only for reason of the entire absence of inertia, and on account of its simple design, the cathode ray oscillograph can be regarded as the ideal measuring appliance. Unfortunately the sensitiveness is, for the present, not sufficiently great, in the case of ordinary measurements to give large enough deflections when the oscillographs are taken directly. When the apparatus is used in conjunction with amplifying gear, these disadvantages can, however, be removed, without this entailing the introduction of inertia.

The measuring apparatus evolved thus constitutes a pressure element, similar to a thermo-couple, by means of which it is possible to measure the pressure at any desired point.

2) See "Bulletin de l'Association Suisse des Electriciens" No. 9, 1928, "On the further development of the cathode ray oscillographs" by K. Berger.

ATELIERS DE CONSTRUCTION OERLIKON, OERLIKON

BULLETIN OERLIKON

No. 111 — September 1930

Contents: Modern trend in Oerlikon steam turbine design.

Notes and News Items: Acceptance tests of a 4750 KW. turbo-set at the Cairo Power Station of Messrs. Lebon & Co., Paris.

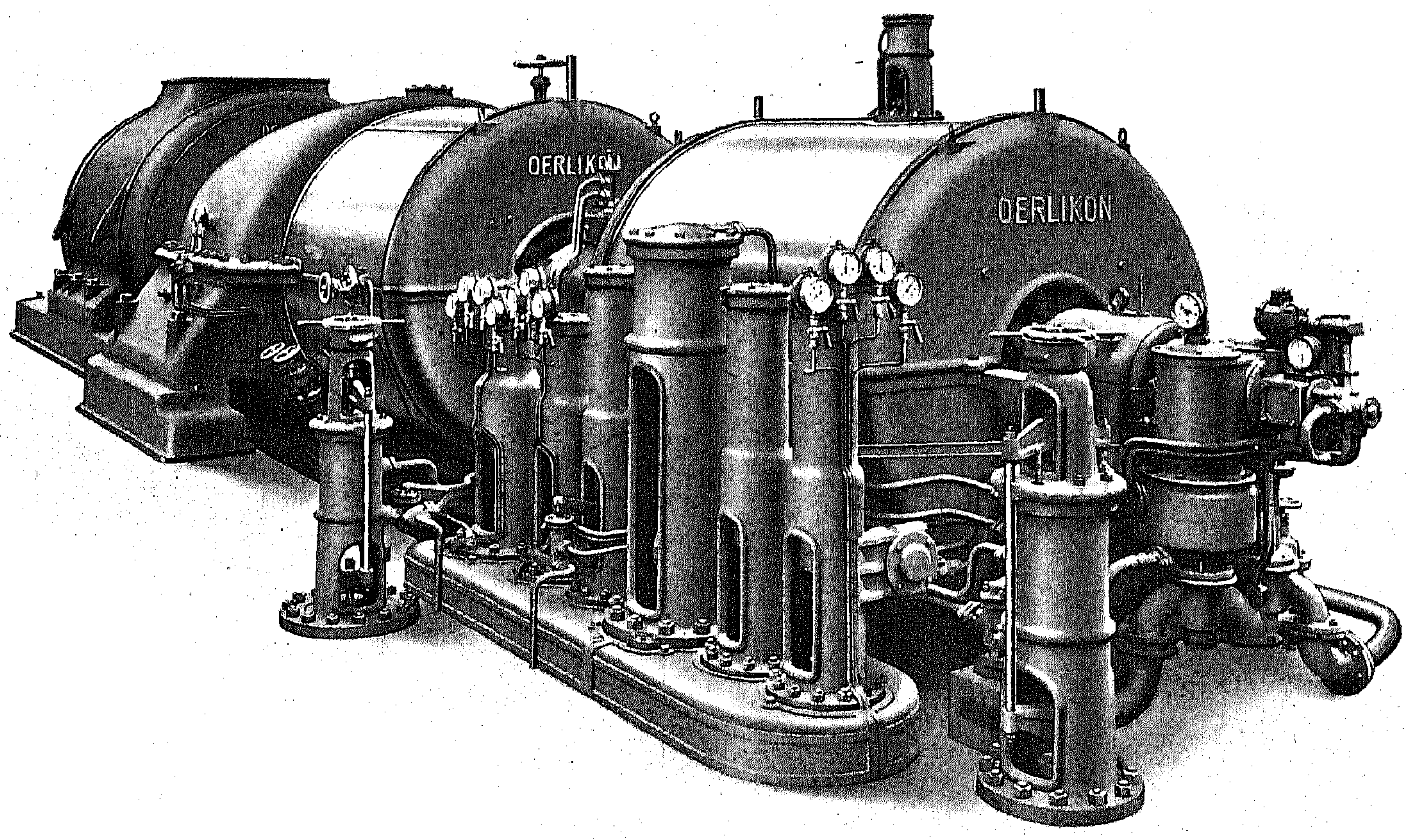


Fig. 1.

Modern Trend in Oerlikon Steam Turbine Design.

The objects aimed at in the latest developments of steam turbine design, namely, the highest possible efficiency or the lowest heat consumption per KWH, with absolute reliability in service, have always been the considerations governing the design of Oerlikon steam turbines. The rise in price of coal, the enormous increase in capacity of the machines and, not least, the fact that it was gradually realised that considerable improvements could be made, and had to be made, in the matter of utilisation of heat, have in recent years, led everywhere to strenuous efforts with a view to reducing the heat consumption. The means available for the purpose are universally known. In first place, the desired object can be sought in increasing the efficiency of the turbine itself, secondly, in providing for a larger available heat drop in the turbine by raising the pressure and the temperature, and, thirdly, by improving the heat process by resorting to regenerative methods and intermediate superheating.

Increasing of efficiency. The Oerlikon steam turbine is an impulse turbine designed with partial admission in the high pressure part and with full admission in the low pressure portion; it may be said to differ from other impulse turbines in regard to the somewhat larger number of stages and especially to the partial admission in the high pressure part. These two distinguishing features ensure, however, exceptional reliability in operation as smaller diameters can be adopted in the high pressure part, owing to the large number of stages, with the result that diaphragms, runners and casing are subjected to smaller stresses and deformations in the region of the high pressure and high temperature. On the other hand, owing to the adoption of partial admission it is possible to make the diaphragms of steel and the blading of stainless steel.

No essential alterations have been made with a view to increasing the efficiency of turbine. All that has been done is to improve the design and increase somewhat the number of stages. Whereas the single-cylinder turbines at 3000 RPM (pressures up to about 285 lbs/sq.in. gauge) were previously built with 10 to 13 stages, the number of stages has at the present day been raised to 12 to 16, the diameter of large units being thereby considerably reduced in the high pressure part.

Flat steam consumption characteristic. In power stations with small and average size units, the turbines are not always fully loaded. Very often, in the night for instance, the load drops to half-load or less. On the other hand, at times of the day when light and power are required simultaneously, the machines have to deal with peak loads and run under overload conditions. It is, therefore, important, from the point of view of the coal consumption of such power stations, that the turbine should not only have a high efficiency at full-load, but that it should also work, under as favourable conditions as possible, at partial load and when overloaded. The object aimed at by the Oerlikon Company, in recent years, has thus been to design the turbines in such a way that the steam consumption should remain constant, within a few percents, over a large range of load; in other words, the end in view has been to obtain a steam consumption characteristic as flat as possible.

This aim has been attained by resorting to the two following measures:— Under overload conditions, the additional steam which was formerly led behind the high pressure stages (Fig. 2) with the result that this steam did not produce any work in the high pressure part and that the efficiency at 5/4 load decreased by about 5 % of full-load value (see Bulletin Oerlikon No. 4, 1921), is led to the first stage too (Fig. 3). In addition to the group of guide channels, 1, which convey the steam for full-load, provision is made for a further group, 2, which leads the steam required for raising the output above normal value, through an automatic valve. This additional steam flows through the first runner to the group of guide channels, 4, for instance, of the third stage, the second runner being by-passed. The valve, which leads the steam to the guide channels, 2, under overload conditions, operates a second auxiliary valve provided in the by-pass channel, 3, which enables the additional steam to flow to the group of guide channels, 4. Up to normal load, the two valves are closed, so that all detrimental effect due to the channels, 2, and, 4, is effectively prevented. The whole drop of the additional steam is thus utilised with the method used by the Oerlikon Company for guiding the overload steam; consequently, the efficiency under overload conditions has approximately the same value as for full-load. The efficiency is somewhat higher or lower according to whether the additional channels are more or less fully loaded and according to the distribution of the drop. The second measure resorted to, namely the improvement of the steam consumption at partial load is well-known. It consists in closing at partial load, part of the normal diaphragm channels of the first stage, by means of valves, so that it is possible to work with full admission pressure at one or several points of partial load too. The Oerlikon Company have been successful in securing considerable improvements at partial load, even with their velocity stages, by constructional means and by ensuring a favourable distribution of drop.

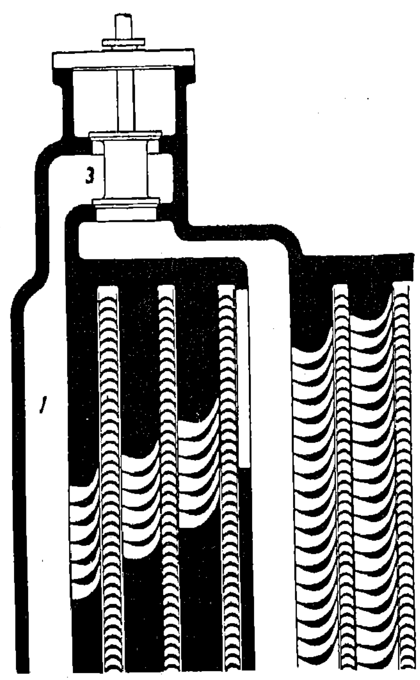


Fig. 2.

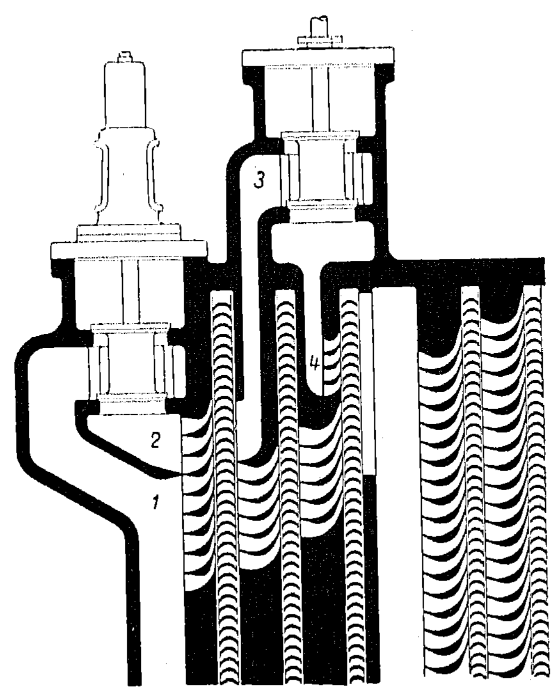


Fig. 3.

Results of tests on single-cylinder turbines. We propose to give here a few results of tests to show the extent to which the efficiency has been increased in modern time and the success achieved in the matter of obtaining a flat steam consumption characteristic, in the case of single-cylinder turbines of small and average output. Table I contains the figures obtained at the acceptance tests of a 2000 KW. Oerlikon turbo-generator set for the Syriam Power Station of the Burmah Oil Co. The tests took place on the 30th and 31st August, 1928 in the test room of the Oerlikon Company. The turbine is designed with admission of the overload steam according to the Oerlikon method described. As can be seen, a somewhat higher efficiency was obtained under overload conditions than at full-load*). The test results in Table II show what effect a favourable regulation of the quantity of steam can have; they refer to a

*) A repeat order has been recently received for 2 further 2000 KW. sets with condensing plant.

	Table I: 2000 KW.- Oerlikon turbo-generator set				**Table II:** 2000 KW.- Oerlikon turbo-generator set			**Table III:** 5000 KW.- Oerlikon turbo-generator set			
Load	5/4	4/4	3/4	1/2	4/4	2/4	1/4	5/4	4/4	3/4	2/4
Steam pressure in front of the turbine, in lbs/sq.in. (gauge)	190.2	196.2	197.0	198.8	207.3	208.7	205.0	197.3	204.4	208.7	211.5
Temperature in front of turbine, °F.	613	647	611	672	651	584	539	714	732	699	689
Vacuum at the inlet of turbine, ins. Mercury	27.02	27.44	27.62	28.13	27.78	28.21	28.49	29.38	29.48	29.56	29.60
Output, KW.	2525	2042.4	1540	1021	1925	1015	510.7	4995	4067	3043	2025
Steam consumption per KWH, lbs.	12.037	11.662	12.478	12.764	11.424	12.315	14.133	9.521	9.440	9.759	10.412
Steam consumption per KWH, kg.	5.46	5.29	5.66	5.79	5.182	5.586	6.411	4.319	4.282	4.427	4.723
Efficiency of generator, %	95.6	95.3	94.8	92.8	95.6	93.4	88.8	96	95.6	94.7	92.7
Efficiency of turbine, %	80.2	79.2	75.3	70.0	78.2	75.4	69.6	77.8	76.6	74.8	71.3
Heat consumption, B.Th.U's.	—	—	—	—	—	—	—	12822	12826	13139	13986

2000 KW. set supplied to the S. A. d'Entreprise Générale de Travaux, Bruxelles, for the Las Palmas Power Station. The acceptance tests took place on the 11th June 1928 also at the Oerlikon Works. A condition laid down in the case of this machine was that the plant should have a specially good efficiency when working at partial load — a requirement which was fully satisfied.

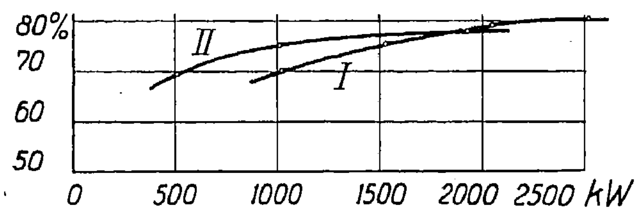


Fig. 4.

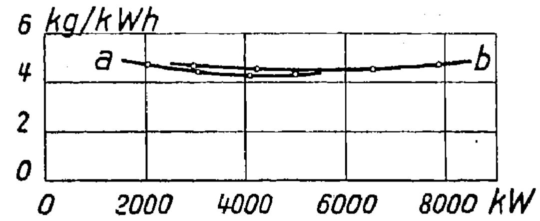


Fig. 5.

In order to be able to compare better the values of turbine efficiencies at partial load given in Tables I and II, the efficiencies have been plotted in the form of curves in Fig. 4. As can be seen there, the efficiency at partial load of Machine II exceeds at certain points that of Machine I to quite a considerable extent, owing to the favourable regulation of the quantities of steam, which is not provided for in the case of Machine I.

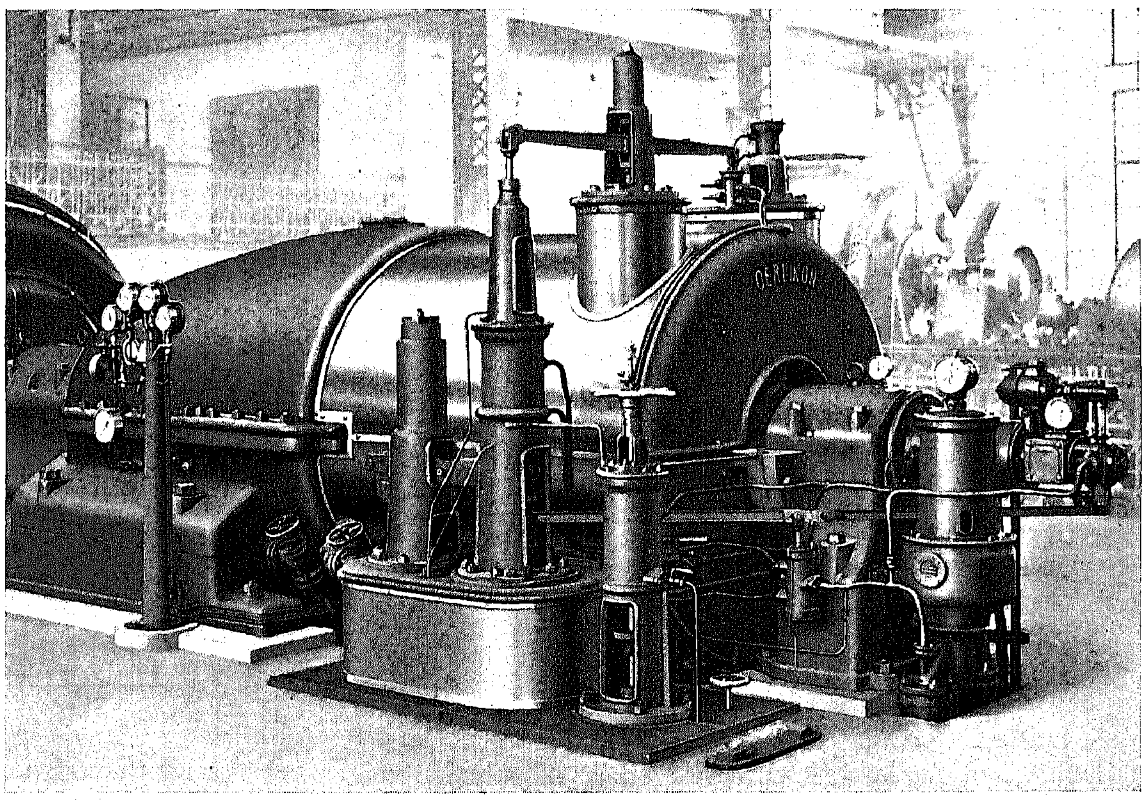


Fig. 6.

Table III contains the test results of a turbine with admission of overload steam according to the Oerlikon method and with regulation of the quantity of steam; it refers to a 5000 KW. turbine which is in service at the Tammerfors Electricity Works. The acceptance tests took place on the 10th November 1928 at Tammerfors and were carried out by the Power and Fuel Research Association of Helsingfors. The turbine was designed for a normal output of 4000 KW and is working, even at 5000 KW, under overload conditions. The turbine efficiencies are relatively low, as the vacuum is considerably higher than that on which the calculations were based; in spite of this, an efficiency of about 80 % was reached. The efficiency under overload conditions is higher than at full-load. The efficiencies at partial load too are high so that the characteristic for the steam and heat consumption is flat over a considerable range of load (Fig. 5, curve a).

Finally, we are giving the results of tests on a 6000 KW. turbine, where the conditions correspond approximately to those upon which the calculations were based. The turbine in question is in service at the power station of Ville-sur-Haine of the Société de Gaz et d'Electricité du Hainaut (Fig. 6). It was supplied to replace an older machine of another make; the efficiencies were, therefore, given at the coupling of turbine and this necessitated exhaustive measurements for the determination of the efficiency of generator. The acceptance tests took place on the 7th and 8th November 1925, under the supervision of Prof. Halleux and Vinçotte. Table IV gives the results obtained.

Table IV: 6000 KW.-Oerlikon turbo-generator set.

Load		5/4	4/4	3/4	1/2
Steam pressure in front of turbine, lbs/sq. in. (gauge)		205.6	201.3	206.7	208.3
Temperature in front of turbine, °F.		658	671.1	677.6	682.5
Vacuum at the inlet of neck-piece of condenser, ins. Merc.		28.24	28.47	29.03	28.94
Output at the coupling of turbine, KW.		7874	6516	4219	2970
Steam consumption per KWH	lbs.	10.471	10.031	10.075	10.361
	kg.	4.75	4.55	4.57	4.70
Efficiency of turbine, %		79	80.3	75.1	73.6

The curve, b, in Fig. 5 shows that the steam consumption characteristic is flat over the large range of load between 3000 and 8000 KW. The steam consumption differs from the average steam consumption only by a little more than ± 2 %.

of 75 % normal load, the steam consumption being, as an average, 10 % higher. This instance, which is one of frequent occurrence, shows that the saving is so great that any power station engineer has to examine whether it would not be advisable for him to replace his turbine by a modern one. Calculations will often show that the cost of a new turbine is paid off in two to three years and that afterwards a substantial yearly saving is ensured. When replacing a turbine, there is no need to consider the question of increasing the pressure to modern values. In installations of small and average capacity, the replacement of the boilers by high pressure boilers is often not justified, as the installation costs of new boilers are very high. The work of replacing a turbine by a modern single-cylinder turbine can, as a rule, be carried out very easily, as only small alterations in the foundations are necessary. The Oerlikon Company have, in recent years, either actually supplied or on order, a number of such turbines for 900 to 14,000 KW. As far as Belgium is concerned, mention can be made of the 6000 KW. turbine for the power station of Ville-sur-Haine. The results of the tests on this machine are given in Table IV.

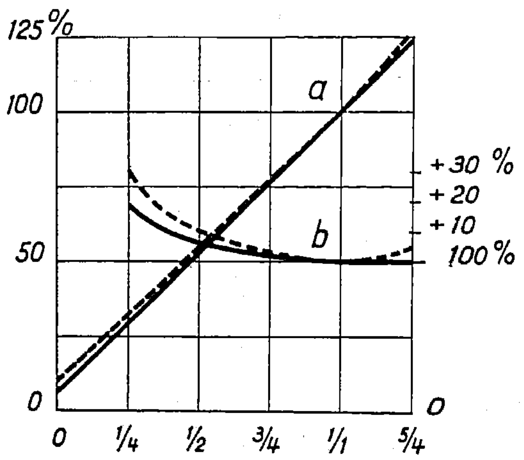


Fig. 7.

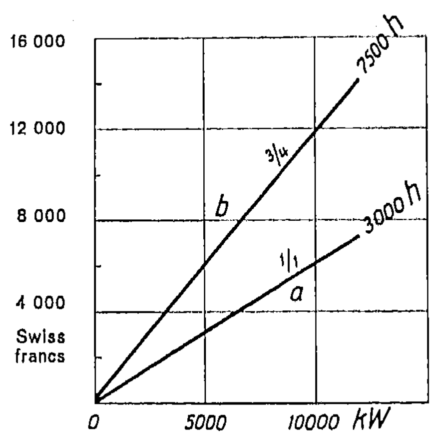


Fig. 8.

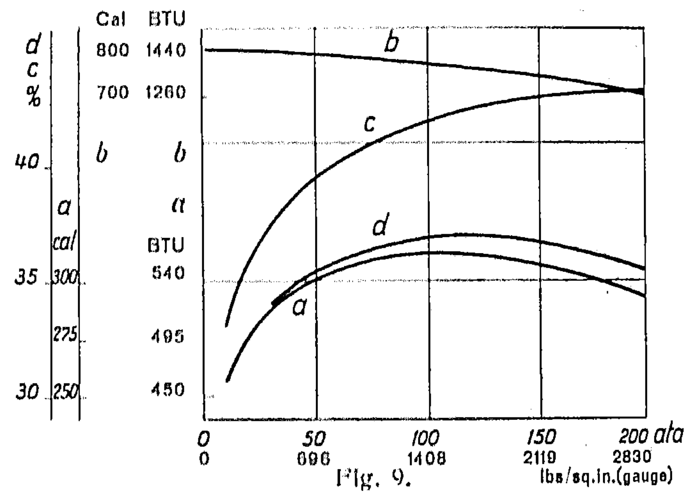


Fig. 9.

Replacement of turbines. Up to a few years ago, efficiencies of 80 % and more and, at the same time, a steam consumption per KWH remaining constant within a few percents, over a very large range of load, were unknown in the case of single-cylinder turbines of small and average capacity. For the purpose of comparison, we give in Fig. 7 curves showing the mode of variation of the hourly steam consumption (a) and of the specific steam consumption (b), in the case of earlier machines (dotted line) and of modern plant (full line).

Machines of small and average capacity work, as a rule, not only at normal load, but have to deal with a load varying often between ¼ and 5/4 load, according to the time of the day and of the night. In such cases it is not only the improvement in efficiency at full-load that affects the coal consumption but also the efficiency at partial load and under overload conditions. In view of this, a modern turbine may permit of an average saving in coal of 10 % and more. The curves in Fig. 8 show, for instance, the approximate saving expressed in Swiss francs, in the case of a turbine of 4000 to 10,000 KW. under the assumption of a steam pressure of 198.8 lbs/sq. in. (gauge), 665° F and a vacuum of 28,5 ins. Merc. Curve, a, shows the saving per year for the case where the machine is constantly running at full-load, for 3000 working hours, the steam consumption of plant being 10 % higher than that of the older machine, while curve, b, deals with the case where the turbine is in operation for 7500 hours per year with an average load

When high pressure boilers are installed, in connection with the extension of a power station, it is, of course, possible, or even necessary, to replace old single-cylinder turbines working at low pressures by modern plant operating at a high pressure. The saving in coal is then still larger than indicated above. The Oerlikon Company have on order a turbine of this description with an output of 10,000 KW for the Pommerœul power station of the Charbonnages d'Hensies-Pommerœul.

Steam turbines for high pressures and high temperatures. The raising of the steam pressure to 1400 lbs/sq.in. and more does not present, for the turbine builder, the great difficulties which were originally anticipated. As a result of the reduction of the diameter of the stages, the casing can be made of cast steel or of steel, with a normal factor of safety. The most awkward parts are the high pressure glands. It is necessary to provide here for the necessary clearance between the stationary and rotating parts and to allow for the corresponding losses in steam.

The raising of the temperature presents greater difficulties, as there are, at the present time, no materials available which permit of the use of temperatures above 840—930 ° F permanently; at least, no test data are available covering long periods of time. At the present day, it is advisable not to exceed a temperature of 840 ° F as normal temperature, so that maximum working temperatures of 890—930 ° F are per-

missible under exceptional conditions. We have plotted in Fig. 9 the heat contents of the steam (curve a), the available heat drop (curve b) and the thermal efficiency (curve c) in function of the steam pressure, for a temperature of 840 ° F and a vacuum of 28.8 ins. Merc. In actual practice, the efficiency does not rise according to the curve c, but follows approximately the curve d (see Bulletin Oerlikon No. 79/80, 1928), owing to the friction and gap losses, which increase with the pressure. The steam pressure cannot, therefore, be increased at will. The efficiency reaches a maximum somewhat below or above 1400 lbs/sq. in., according to the output of the machine.

The proportion of heat drop in the region of superheat and the wetness of the steam at the turbine outlet are factors which have a deciding influence on the value of efficiency attainable. A higher degree of wetness can also cause erosion of the blading of the last stage. In Fig. 10, we have plotted the proportion of the available heat drop in the region of superheat (curve a) and the degree of wetness of the steam at the turbine outlet, in the case of steam expansion without loss (curve b), in function of the steam pressure, for a temperature of 840 ° F and a vacuum of 28.8 ins. Merc. The horizontal line passes through the point where the proportion of heat drop in the region of superheat is 40 %, and the degree of wetness is .8. In the region above this horizontal line, we have the pressures with which high efficiencies have been obtained up to now and the durability of the blading should be assured. The highest values of these steam pressures would be 700 to 1000 lbs/sq. in., of course, without intermediate superheating.

For a power station engineer, it is not only a question of installing a machine with the highest possible efficiency, i. e. with the lowest heat consumption, but it is a matter of choosing the machine which represents the lowest capital outlay per KWH. When the steam pressure is increased, this affects a number of factors which themselves influence capital expenditure. The price of the boiler, for instance, increases very considerably, and the price of the turbine and the cost of building also, to a lesser degree. As soon as the pressure is above 1000 lbs/sq. in. and intermediate superheating is resorted to, the cost of boiler rises still further, as a result of this intermediate superheating; it, thus, follows that the economical pressures are considerably lower than those given by the curve, d, in Fig. 9. Even for relatively low outputs, above 4000 KW, pressures of about 500 lbs/sq. in. appear to be economical. When the unit is large, the price of coal high, and duration of service throughout the year, long, the economical pressure should be between 750 and 1000 lbs/sq. in.

Owing to the small number of high pressure boilers built up to now, the prices are not yet stabilised; on the other hand, the test data regarding high pressure turbines is still limited so that an actual determination of the economical pressure is not yet possible, at the present day.

Design of the Oerlikon high pressure steam turbine. The Oerlikon high pressure steam turbine differs from the standard turbine only insofar as its dimensions are smaller and the casing is of cast steel or of special cast steel in the case of temperatures above 800 ° F. The throttle valves are arranged on the side of the casing and independently of it; they are connected to the casing by means of flexible pipe connections.

Owing to this, stresses due to the steam pipes are not communicated to the casing. For the glands on the shaft,

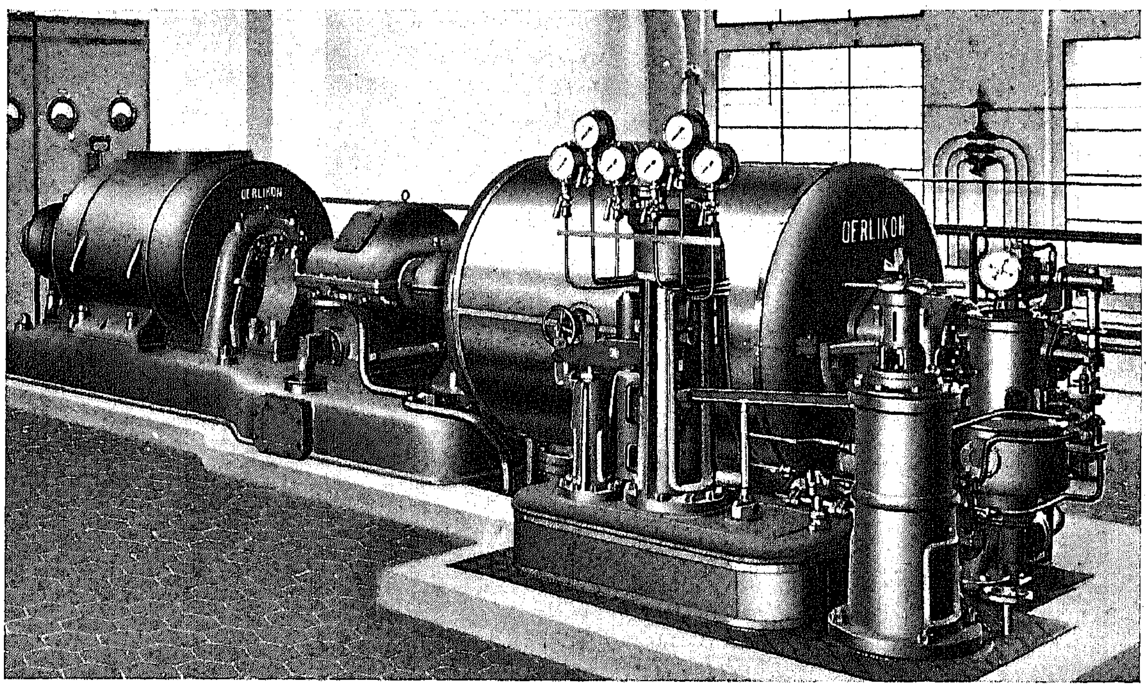


Fig. 12.

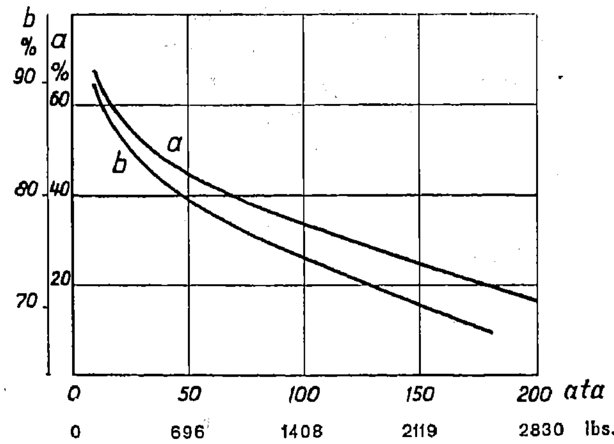


Fig. 10.

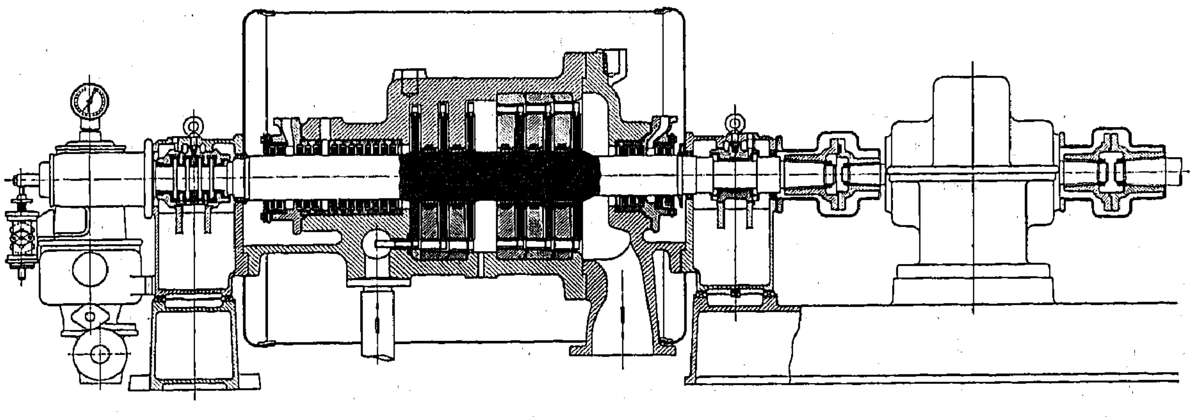


Fig. 11.

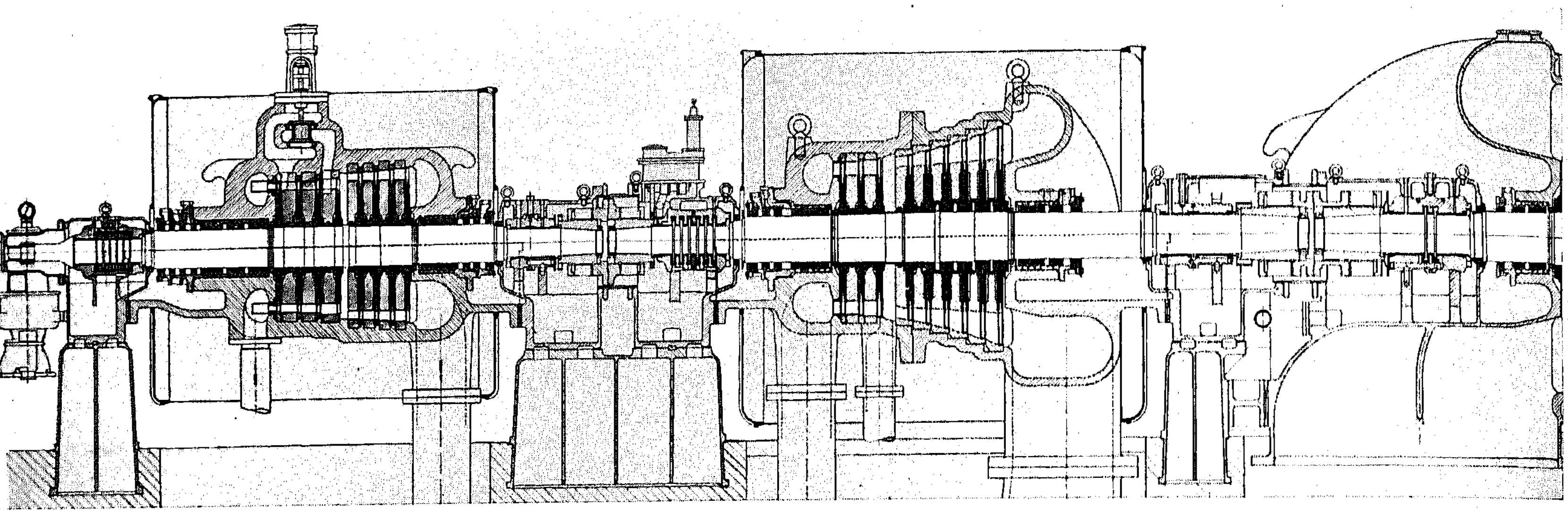


Fig. 15a.

use is made of specially designed carbon rings, which have given very good results. Fig. 11 is a section through an 850 KW high pressure turbine running at 6800/3000 RPM, built for a pressure of 455 lbs/sq.in.(gauge). In the case of the first three stages, the steam is admitted only along the lower halves, the upper partitions being cast in one piece with the upper part of the casing. The turbine has been in operation since May, 1929, in the Widnau Power Station of the Société de la Viscose, Switzerland (Fig. 12).

Fig. 1 represents a 20,000 KW two-cylinder high pressure turbine built for 455 lbs./sq.in.(gauge) and 750° F. The turbine had also to be suitable for operation with a pressure of 200 lbs/sq.in. and a temperature of 660° F. The inlet and throttle valves for both pressures, which are mounted independently of the casing, can be seen at the side of the latter; they are arranged in such a way that the HP valves open first. Fig. 13 shows a special turbine design. The machine in question is a 2500 KW. turbine supplied to the Usines E. Henricot at Court-St. Etienne; it is built for a pressure of 355 lbs/sq.in.(gauge) and a temperature of 710° F. The turbine was originally ordered for 135 lbs/sq.in. (gauge) and 570° F, under which conditions it was only to develop 2000 KW. In the case of this lower pressure, the two first runners were not provided, and the runners 3 to 5, were shifted forwards, as can be seen from Fig. 14.

Limit outputs. The limit output of a turbine is fixed by the volume of steam in the last stage, that is to say, by the weight of steam and by the vacuum. In the case of large units, the vacuum varies between 28.2 and 29.1 ins. Merc., according to the temperature of cooling water. When use is made of water which is led back through cooling plant, or of warm river water at 81 to 86° F, the limit output is thus approximately twice that for fresh water at 50 to 54° F. As a rule, the length of the blading of the last stage is taken equal to 25 % of the average diameter of admission, at the most. The limit output is obtained for the peripheral speed, where it is still just possible for the designer to obtain the desired safety against breakage of the last blading. There is no fixed value for the factor of safety. Some designers are content with a figure of 3.5, while others require at least a factor of safety of 5. In view of this, the limit output for 3000 RPM machines varies between 12,000 and 20,000 KW, for a low pressure machine. When the pressure of steam is raised, the available heat drop increases (Fig. 9) and consequently, the limit output too. The limit output is also raised by resorting to regenerative methods, as part of the steam is drawn away before the last stage.

The limit output is not only fixed by the turbine but also by the generator coupled to it. In recent years, the capacity of generators has been increased very considerably; at the present day, there are generators for 50,000 KW at 3000 RPM in course of construction. This means that the limit output of generators has passed that of the turbine with single steam outlet very considerably. In order to meet the case, the turbine designer has first resorted to the well-known measure of dividing the flow of steam, in the last stages, into two halves and the most varied types of two-flow turbines have been built.

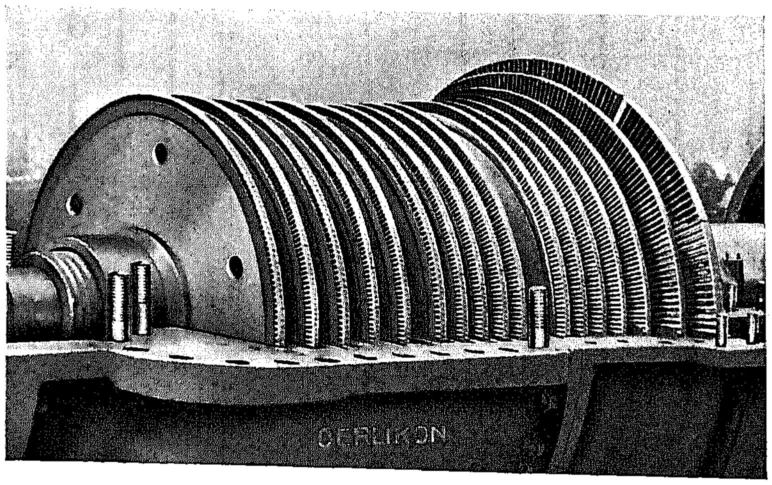


Fig. 13.

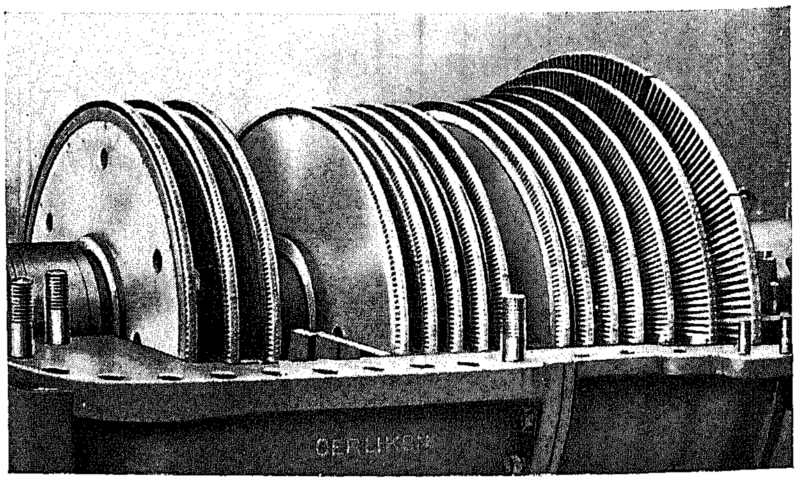


Fig. 14.

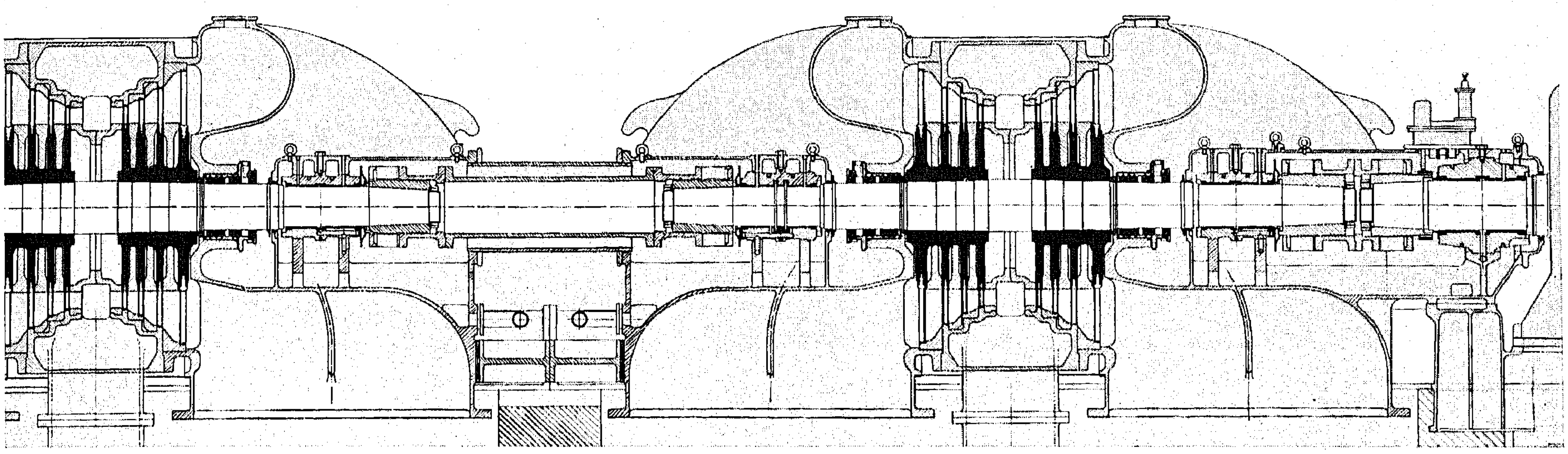


Fig. 15b.

But even the sub-division into two halves is not sufficient, at the present day, for high vacua. In the case of large units, the question of economical operation must be examined. There are turbines with peripheral speeds of 820—950 ft/sec., in the last stage, which work perfectly well. The outlet velocity of the steam is then 540—655 ft/sec. In the case of a heat drop of 540 B.Th.U's/lb, this represents a figure of 1.15 to 1.6 %, which amount has to be regarded as a loss. In the case of a unit of 50,000 KW, however, even an increase of 0.5 % in the coal consumption plays an important part and it is, therefore, necessary to investigate the question of limit output for large units also from an economical point of view.

In Bulletin No. 75, of 1927, the Oerlikon Company set out a design for a 3-flow, 3-cylinder turbine for 40,000 KW at 3000 RPM. At the present day, they have a 4-flow, 4-cylinder turbine for 50,000 KW at 3000 RPM in the course of construction. The turbine (Fig. 15) is intended for the St. Denis Power Station of the Société d'Electricité de Paris. It is a high pressure turbine for a normal pressure of 750—850 lbs/sq. in. (gauge), a temperature of 840—890 ° F and a vacuum of 29 ins. Merc. The high pressure casing is made of special cast steel, the high pressure part of the middle pressure turbine of perlite and the two low pressure casings of special cast iron. The adoption of 4 outlets made it possible to reduce the average peripheral speed of the last stage to 800 ft/sec., i.e. a value which is very much safer than that for units built up to now.

In view of the high capacity of the 3000 RPM generator, special provisions have been made for safety devices on the turbine. There are, for instance, three emergency devices for protecting the plant against racing. The first emergency governor is on the high pressure shaft, the second one on the middle pressure shaft and the third on the low pressure shaft. The turbine has two main valves arranged in series, upon which the governor of the high pressure shaft and of the low pressure shaft act. The Oerlikon Company hope that in this way, sufficient protection will be provided against racing, even for sets with limit outputs.

The arrangement of a set for 50,000 KW at 3000 RPM in one line was first proposed by the Oerlikon Company for the St. Denis Power Station. The turbine in question has to work, under exceptional conditions, with a pressure of 1000 lbs/sq. in. (gauge) and a temperature of 930 ° F. For such conditions the high pressure part would, in any case, have been built for 3000 RPM. In the case of a cross-compound arrangement, the low pressure part could have been built as a two-flow turbine running at 1500 RPM; the capital expenditure for the turbine would, however, have been more than 50 % higher.

As the turbine in question has still moderate peripheral speeds in the last stage, it is in no way a turbine with limit output, from a constructional point of view, and the Oerlikon Company is in a position to build 4-flow turbines and generators up to a capacity of 75,000 KW at 3000 RPM. Fig. 16 shows such a set with 4 condensers; the total length is 105 ft.

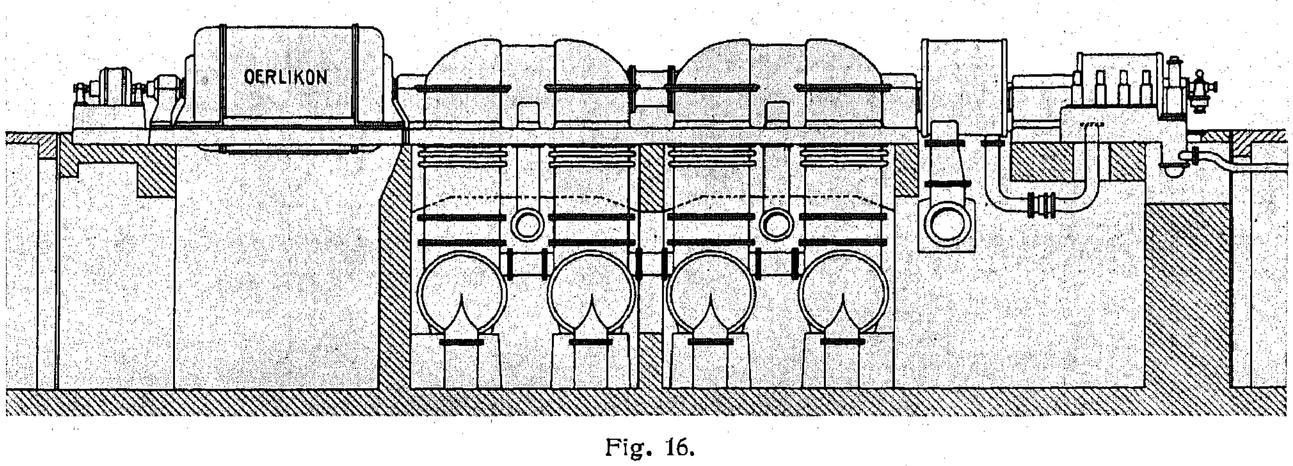
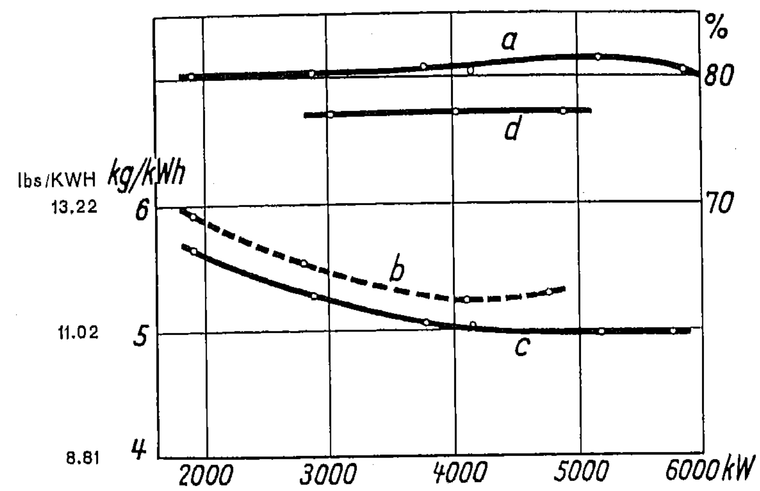


Fig. 16.

Notes and News Items.



Acceptance tests of a 4750 KW. turbo-set at the Cairo Power Station of Messrs. Lebon & Co., Paris. The distribution system of this power station is for a frequency of 40 cycles, but may be converted later on for operation at 50 cycles. In view of this, the turbo-sets supplied by the Oerlikon Company, in recent years, have been built in such a way that they can run at 2400 and 3000 RPM.

The official acceptance tests of the last set supplied, which has an output of 4750 KW, took place on the 28th March and 3rd April, 1930, under the supervision of Professor Rutgers of the Cairo Technical College. The turbine is built for a pressure of 185 lbs/sq.in.(gauge), a temperature of 660° F, and a vacuum of 2.32 ins. Merc., under which

4750 KW. Turbo-alternator	Tests at 3000 RPM.						Tests at 2400 RPM.		
Load KW	1904.6	2891.2	3771.8	4147.6	5169.6	5765.4	3020.7	4021.4	4878.7
1) Duration of tests . . . . min.	60	60	30	60	60	50	30	30	30
2) Pressure in front of turbine lbs/sq. in. (gauge)	211.0	199.1	190.6	194.5	189.8	192.2	200.5	185.4	192.4
3) Temperature in front of turbine . . . . . °F	611.6	618.8	610.1	631.5	619.5	636.2	580.6	590.7	586.0
4) Pressure in front of the nozzles lbs/sq. in. (gauge)	70.1	106.6	141.3	153.6	175.2	185.1	110.9	185.4	189.8
5) Vacuum at condenser flange . . . Ins. Merc.	28.66	28.44	27.85	28.12	27.43	27.96	28.644	28.37	28.05
6) Temperature at outlet of turbine . . . . . °F	87.0	92.6	104.1	99.8	109.4	100.9	88.3	93.3	99.6
7) Temperature of condensed steam . . . . °F	88.98	93.7	103.6	100.5	108.59	100.9	90.1	94.1	100.13
8) Steam consumption . . . . lbs/hr.	24425	34650	54011	47480	59915	64070	37425	48032	58177
9) Specific steam consumption . . . lbs/KWH	12.822	11.984	11.933	11.446	11.589	11.111	12.387	11.942	11.924
10) Efficiency of set based on 2), 3) and 5) . . %	63.9	69.8	73.95	74.3	77.4	77.1	67.9	72.2	73.9
11) Efficiency of set based on 4) . . . . %	74.3	76.1	77.2	76.9	78.3	77.6	73.6	74.4	74.5
12) Efficiency of alternator . . . . %	92.45	94.65	95.55	95.7	96.14	96.3	95.4	96.3	96.5
13) Efficiency of the turbine based on 4) and 5) . %	**80.35**	**80.4**	**80.8**	**80.4**	**81.45**	**80.55**	**77.1**	**77.25**	**77.2**

conditions the turbine has a normal output of 4100 KW at 3000 RPM. The turbine must be capable of dealing with an overload of 5700 KW; use is made of the special Oerlikon method of admitting the overload steam.

The readings taken at 3000 RPM are given in the Table. Curve (a) in the accompanying chart gives the turbine efficiencies referred to the steam conditions in front of the first stage. Between 1900 and 5800 KW, the efficiencies reach approximately the value of 80 % and even exceed it. The highest value was obtained under overload conditions for an output of 5169 KW, the figure obtained being 81.45 %. Curve (b) gives the guaranteed steam consumption figures and curve (c) the test figures, converted to their equivalent values for the conditions laid down in the contract, the latter values being considerably more favourable. Between 3800 and 5800 KW, the steam consumption remains constant within the limit of 1½ %.

The readings taken at 2400 RPM are also given in the Table. Curve (d) gives the turbine efficiencies obtained; these efficiencies are 3 to 4 % lower than at 3000 RPM (Curve a).

The first Oerlikon turbine supplied for the Cairo Power Station was installed in 1908; it had an output of 3150 KW at 1200 RPM and was designed for a pressure of 155 lbs/sq.in.(gauge), with dry saturated steam, and for a vacuum of 26.23 ins. Mercury. The guaranteed steam consumption per KW-hour was 21.16 lbs., and the turbine efficiency 60 %, while values of more than 80 % are reached at the present day with sets not much larger than the machine in question.

ATELIERS DE CONSTRUCTION OERLIKON, OERLIKON

BULLETIN OERLIKON

No. 112 – October 1930

The Diagram of Differential Protection.

By F. Becker.

Summary. In the present study, a brief description is given of the working diagram of the differential protection and, on the basis of this diagram, the working characteristics for the differential protection are plotted for overload conditions. It is shown, in particular, that the fact of having identical characteristics for the current transformers does not afford an absolute guarantee as to the reliability of the protection, as the degree of sensitiveness varies with the load. Furthermore, in the case of heavy overloads, the effect of the higher harmonics of the magnetising currents makes itself felt; this effect can, however, be reduced by adopting a suitable design for the current transformers. It is further pointed out, that differences in the secondary resistances or dissimilarities in the magnetising curves of the current transformers may affect the factor of safety. It is also shown that a small percentage fault in the transformation ratio of the current transformers suffices to render the differential protection useless.

1) Introduction. When large generators or transformers have to be taken out of service owing to defects, this may result, in certain cases, in great losses to the electric supply company, as, apart from the heavy expenditure necessitated by the repairs, there is a large falling off in power supply. For these reasons and in view of the growing practice to instal large units, renewed attention has been paid in recent years to the Merz-Price differential method of protection. With this scheme of protection, it is possible, by using relays with a high degree of sensitiveness, to deal with faults at the very moment they develop, this being a matter of special importance as the damage to the windings and to the core is then reduced to a minimum. Furthermore, differential protection satisfies also the requirements of selectivity as it depends for its operation only upon the fault current within the range of protection. When use is made of relays operating instantaneously, or at least of relays with a very small time lag, it is possible to cut out a faulty circuit before the stability of the rest of the installation is endangered.

In spite of these remarkable properties afforded by differential protection, cases are often encountered where, owing to the current transformers being incorrectly chosen and dimensioned, the differential relays cause the release of circuit breakers wrongly, even when the defect is outside the range of protection of the differential protective equipment. In view of this, not only is the selectivity of the differential protection impaired, but there is also, as a result, uncertainty as regards faults in the object protected. For this reason, it is necessary to study more in detail, by means of working diagrams, the behaviour of differential protection under overload conditions.

If we look through the technical literature and consider the very varied arrangements suggested for differential protection — arrangements which are based, in most part, on the Merz-Price system — we find only relatively few instances where this subject is investigated theoretically or by tests. The question of the protection of lines by the Merz-Price system was dealt with in a very exhaustive way by Prof. K. Kuhlmann, in the important paper he contributed to the „Archiv der Elektrotechnik" 1913, Volume I, page 110, while interesting data are given by Dr. F. Ahrberg and W. Gaarz in the „Wissenschaftl. Veröffentlichungen" of the Siemens Concern, Volume IV, No. 2, and Volume V, No. 1, regarding the protection of generators and transformers.

We propose, therefore, to investigate in the following study, the mode of operation of differential protection, and to examine the influence of the magnetic conditions in the current transformers and also of the other electrical quantities in the differential circuit. As the magnetising characteristic cannot be represented mathematically by a simple equation, we have to determine the working data graphically point by point. The way to deal with the problem is to determine, for a given relay and secondary current, the EMF's induced in the two current transformers and then to derive the corresponding magnetising currents from the magnetising characteristics of the current transformers point by point. The primary current required for the operation of the relay is then obtained by adding these currents to the relay current.

When use is made of highly saturated current transformers, it may, however, happen that the values obtained in this way differ considerably from those measured, as the magnetising currents of the current transformers differ greatly from a sine-shaped curve, in the case of heavy overloads. With a given sine-shaped pressure, the r.m.s. values of the magnetising currents of two current transformers may actually be equal. The curve shapes may, however, differ quite considerably in relation to each other, so that the currents of higher frequency equalise each other through the differential relay. We propose to show hereafter, by means of test data, the influence of the higher harmonics.

2) Mode of operation of the Merz-Price Differential Protection. We can distinguish two modes of differential protection which differ in principle. One of these is used mainly for the protection of lines and is based on the comparison of the secondary EMF's of current transformers specially designed for the purpose. As can be seen from Fig. 1a, the secondary windings of the current transformers are connected in series through a sensitive differential relay, in such a way that the EMF's induced in the secondary windings neutralise each other during normal service. It is only when a fault current occurs that the EMF of one of the current transformers overbalances that of the other current transformer and causes the operation of the differential relay.

The other method, which we propose to examine here more in detail, is dealt with in Fig. 1b; it is applied specially for the protection of generators and transformers. It differs from the first method in that it is based on the comparison of the secondary currents of ordinary current transformers; the differential relay is bridged in parallel across the secondary windings of the current transformers. The relay operates only when the equilibrium of the secondary currents is disturbed as a result of a fault.

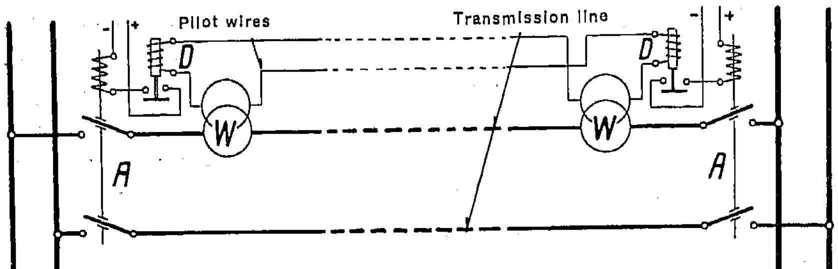


Fig. 1a. Differential protection as applied to a single-phase transmission line.
A = Oil circuit breaker. W = Current transformer. D = Differential relay.

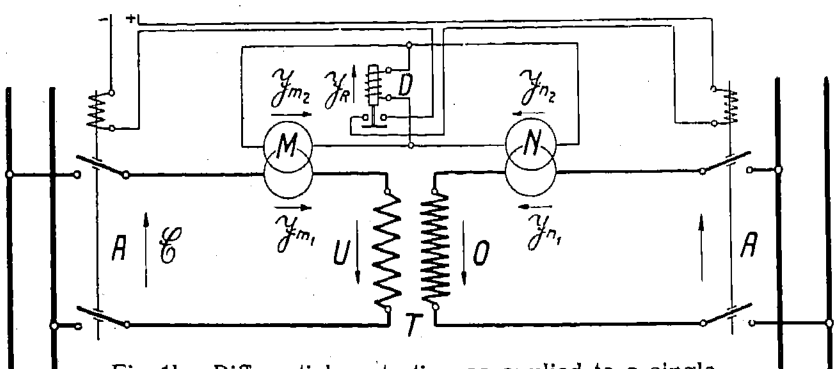


Fig. 1b. Differential protection as applied to a single-phase transformer.
A = Oil circuit breaker. M, N = Current transformers. D = Differential relay. T = Power transformer. U, O = Low and high tension windings.

According to the arrangement in Fig. 1a, the current transformers operate during normal service under no-load conditions, while according to the mode of connection shown in Fig. 1b, they work under short-circuit conditions, so that measuring instruments and overload relays can also be fitted in the differential circuit, if required. We are representing, hereafter, all diagrams of connections as single-phase diagrams; we shall assume that the mode of applying these diagrams to three-phase systems, as well as the manner of choosing the ratio and connections of current transformers, are known.

Before calculating the working currents and EMF's for the arrangement shown in Fig. 1b, we shall fix the positive direction of the different quantities to be introduced in our formulae by means of arrows. We shall further assume that all the resistance EMF's ($-\mathfrak{J}r$) in the time vector diagram are to be plotted as counter-EMF's in opposition to the corresponding current. The EMF's induced by magnetic fields will have to be shown as lagging behind the corresponding flux and current by 90°, and the capacity pressures as leading by 90°.

According to these notations, a circuit absorbs energy when the phase angle between the current and the sum of the pressures acting in this circuit is an obtuse angle. We shall take as direction of rotation for the time vectors of the currents and pressures, the counter-clockwise direction *).

We can thus write the following equation for the secondary circuit of the current transformers in Fig. 1b: —

$$\mathfrak{J}_R = \mathfrak{J}_{m_2} + \mathfrak{J}_{n_2} \qquad (1)$$

If we take, for the current transformers M and N, as well as for the power transformer T, a transformation ratio $= 1$, we arrive at the following expressions for the magnetising currents of the current transformers: —

$$\mathfrak{J}_{am} = \mathfrak{J}_{m_1} + \mathfrak{J}_{m_2} \qquad (2)$$

$$\mathfrak{J}_{an} = \mathfrak{J}_{n_1} + \mathfrak{J}_{n_2} \qquad (3)$$

We then obtain the relay current by adding these two equations: —

$$\mathfrak{J}_R = (\mathfrak{J}_{am} + \mathfrak{J}_{an}) - (\mathfrak{J}_{m_1} + \mathfrak{J}_{n_1}) \qquad (4)$$

In the case of the protection of generators, the vectorial sum $(\mathfrak{J}_{m_1} + \mathfrak{J}_{n_1}) = 0$, when there is no disturbance in the circuit; in the case of the protection of transformers, however, this sum is equal to the magnetising current of the protected transformer. For $(\mathfrak{J}_{m_1} + \mathfrak{J}_{n_1}) = 0$, the quantity $\mathfrak{J}_R$ is, apart from higher harmonics, also equal to zero when the sum of the magnetising currents $(\mathfrak{J}_{am} + \mathfrak{J}_{an})$ is equal to zero, i. e. when the magnetising curves of the two current transformers coincide.

If we designate by ΔI the value of the disturbance current $\Delta \mathfrak{J} = (\mathfrak{J}_{m_1} + \mathfrak{J}_{n_1})$, which is just sufficient for the operation of the differential relay and by I_N, the normal working current, we can express the degree of sensitiveness σ_e of the differential protection as follows: —

$$\sigma_e = \frac{I_N}{\Delta I}$$

We shall define the factor of safety in a similar way as the ratio between the largest possible overload current rush, for which the relay just operates, and the normal working current:

$$\sigma_s = \frac{I_K}{I_N}$$

These two characteristic quantities of the differential protection are, as shown by the equation (4), dependent upon the magnetising currents of the current transformers and upon the shape of the magnetising curve.

Let us now draw the vector diagram (Fig. 2 a), where we shall represent the given relay current $\mathfrak{J}_R$ by the vector OA. We shall further plot the vector of the secondary current $\mathfrak{J}_{m_2} =$ OB, for a condition of load chosen arbitrarily, and shall make it lead over the relay current $\mathfrak{J}_R$ by an angle θ; we thus obtain, according to the equation (1), the current vector $\mathfrak{J}_{n_2} =$ AB. If we now add all the pressures for the two parallel sections of the secondary circuit, we have, according to the Kirchhoff Laws, the following equations:

$$\mathfrak{E}_m - \mathfrak{J}_R \mathfrak{Z}_R - \mathfrak{J}_{m_2} \mathfrak{Z}_2 = 0 \qquad (5)$$

$$\mathfrak{E}_n - \mathfrak{J}_R \mathfrak{Z}_R - \mathfrak{J}_{n_2} \mathfrak{Z}_2 = 0 \qquad (6)$$

where $\mathfrak{E}_m$ and $\mathfrak{E}_n$ represent the EMF's induced by the main field of the current transformers M and N and $\mathfrak{Z}_R = (r_R + jx_R)$ and $\mathfrak{Z}_2 = (r_2 + jx_2)$, the impedance of the relay and the impedance

*) All vectorial quantities are indicated by gothic letters.

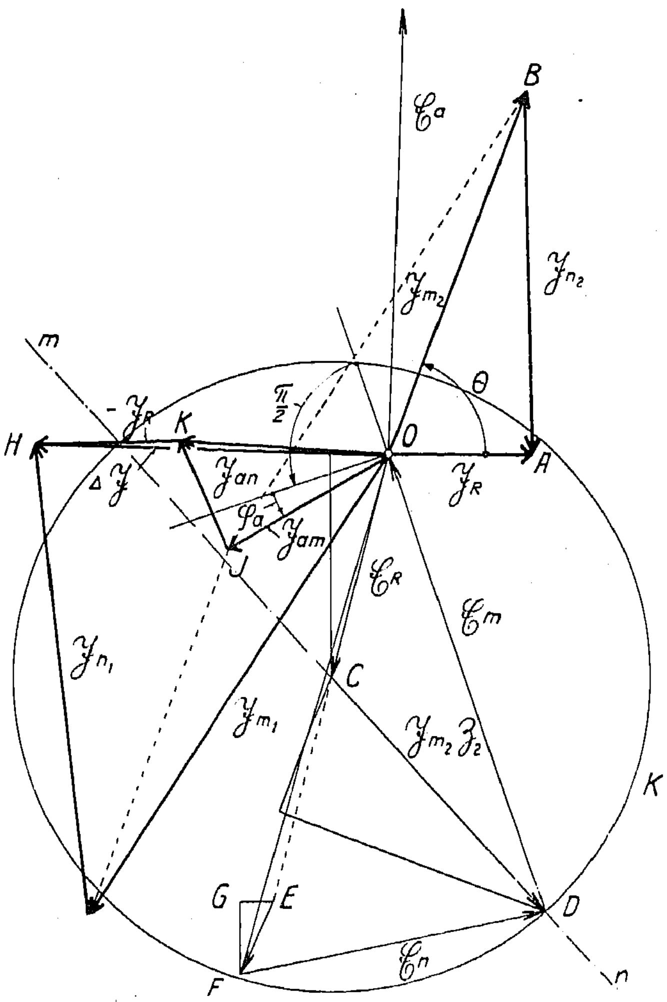


Fig. 2a. Vector diagram of differential protection.
The winding U of the power transformer draws energy.

resulting from the resistance of the secondary circuit and the leakage reactance of the current transformers, the assumption being made, in first place, that the latter are of the same order of magnitude for both current transformers. If we plot the quantities contained in the equation (5), in the vector diagram in Fig. 2a, the line that closes the pressure triangle OCD gives the pressure $\mathfrak{E}_m = OD$ induced in the current transformer M both in value and direction. We can then obtain the corresponding magnetising current $J_{am} = OI$ from the magnetising curve. We plot this quantity in the vector diagram and make it lead over $\mathfrak{E}_m$ by an angle $\left(\frac{\pi}{2} + \varphi_a\right)$. The angle φ_a is the angle of losses corresponding to the iron losses of the current transformer. On the other hand, we arrive at the following equation by adding the equations (5) and (6) and by making use of the equation (1):

$$\mathfrak{E}_m + \mathfrak{E}_n - J_R (2\,\mathfrak{Z}_R + \mathfrak{Z}_2) = 0$$

If we plot in the vector diagram the vector $-J_R (2\mathfrak{Z}_R + \mathfrak{Z}_2) = OF$, the line that closes the pressure polygon OEFD gives the desired vector representing the EMF $\mathfrak{E}_n = DF$ induced in the current transformer N by its main field. The magnetising current $J_{an} = IK$ corresponding to this pressure leads over the pressure $\mathfrak{E}_n$ by an angle $\left(\frac{\pi}{2} + \varphi_a\right)$. According to the equation (4), the disturbance current is thus $\Delta J = OH$. If we alter the load of the transformer, the angle θ being kept constant, the quantity $-J_{m_2} \mathfrak{Z}_2$ varies in the same ratio as the load, that is to say, the point D moves along the straight line Cn. For no-load conditions where $J_{m_2} = 0$, the point D coincides with C; the pressure $\mathfrak{E}_m$ is equal to the relay pressure $\mathfrak{E}_R$ and is in opposition to the latter. If we neglect the pressure drop $-J_R \mathfrak{Z}_2$, which is, as a rule, negligible, the same applies to the pressure $\mathfrak{E}_n$.

The quantity ΔJ can be determined in the manner indicated, point by point, for a constant phase angle θ and for any desired load. As the disturbance current is, in the case of a sound transformer, equal to the magnetising current of the latter, it leads over the pressure induced in the transformer by an angle $\frac{\pi}{2}$, if we neglect the iron losses. In the case we are dealing with in Fig. 2a, the induced pressure $\mathfrak{E}_a$ forms, therefore, with the primary current J_{m_1} an obtuse angle; this means, in view of the notations previously adopted, that the winding U of the transformer draws energy. On the other hand, in the case of the diagram in Fig. 2b, the winding U supplies energy, that is to say, the passage of the point D through the no-load point C is equivalent to the reversal of the direction of flow of energy in the power transformer.

It is also possible to obtain without difficulty, by means of the vector diagrams in Figs. 2a and 2b, the quantity ΔJ, for a constant load current J_{m_2} and a variable angle θ, by revolving the vector $-J_{m_2}(r_2 + jx_2) = CD$ about C as centre. The extremity of the vector $\mathfrak{E}_n$ and the origin of the vector $\mathfrak{E}_m$ then move along the circle K in Fig. 2a.

The determination point by point of the operating curves entails, as can easily be seen, a considerable amount of work; in addition, there is, with this method, a certain difficulty in obtaining a comprehensive survey of the conditions. A more rapid method and one affording better facilities for surveying the conditions, is that where the magnetising curve of the current transformers is split up into several rectilinear sections which only cover a limited range of load. The magnetising

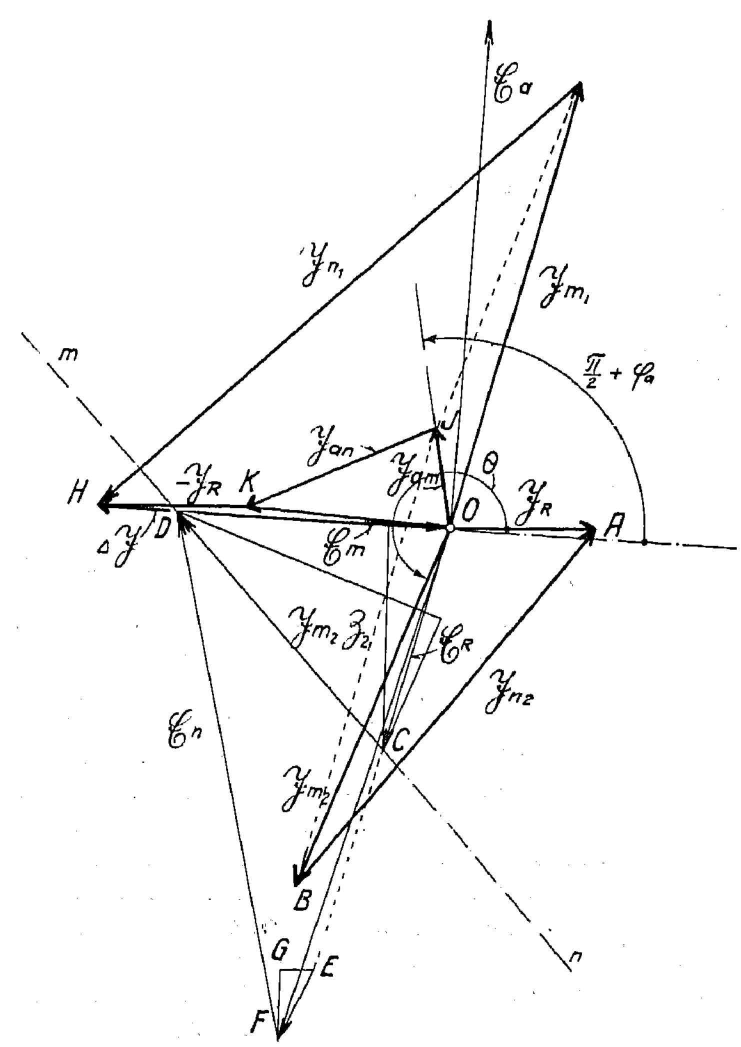


Fig. 2b. Vector diagram of differential protection.
The winding U of the power transformer supplies energy.

curve F, in Fig. 3 can, for instance, be replaced, with considerable accuracy, by a straight line over the range A – B. If we draw through the origin of the co-ordinates a line OC parallel to AB, it is possible to resolve the magnetising current into a component J'_a proportional to the pressure and a component J''_a which is constant for the range in question. The latter component is given by the distance from the origin to the point of intersection of the line AB with the axis of the abscissae. In the present case, the total magnetising current is thus equal to $J_a = J'_a + J''_a$. In the case of a higher saturation of the current transformers, the point of intersection of the line A′ B′ is situated on the negative axis of the abscissae; the total magnetising current is then $J_a = J'_a - J''_a$.

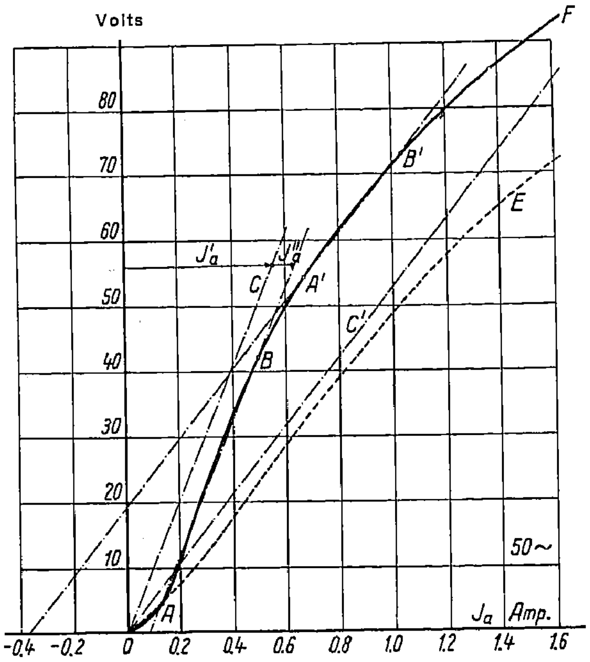


Fig. 3. Magnetising curve of current transformer for 6000 volts, 10/5 amps.
F = without air gap, E = with air gap of 1 mm.

We shall now apply this method of sectionalising the magnetising curve and shall once more draw a working diagram in Fig. 4; in this connection, we shall neglect, however, entirely the small impedance triangle EGF (Fig. 2a). We shall designate by J'_{am} = OF and J'_{an} = FG the magnetising currents of the current transformers M and N, the latter being based upon the straight magnetising line OC (Fig. 3), such as would be obtained if the permeability of the core of the current transformers were constant. We now add to these two magnetising currents the constant components J''_{am} and J''_{an} corresponding to the range of load in question. In the working diagram in Fig. 4, J'_{am} and J'_{an} lead over the pressures $\mathfrak{E}_m$ and $\mathfrak{E}_n$ by an angle $\left(\frac{\pi}{2}+\varphi_a\right)$. On the other hand, as these magnetising currents are proportional to their corresponding pressures, the triangle OFG is similar to the triangle OED. As, furthermore, OE = 2 $\mathfrak{E}_R$ is constant for a given relay current, the quantity OG also remains constant under the same assumptions. We thus see that the disturbance current ΔJ, and, consequently, the degree of sensitiveness too, remain constant when the magnetising characteristic is rectilinear and the relay current is constant, no matter the value and phase of the secondary currents J_{m_2} and J_{n_2}. We can resolve the magnetising current J'_{am} = OF into the component OK which corresponds to the relay pressure $\mathfrak{E}_R$ and the component FK which corresponds to the internal pressure drop $J_{m_2} \times \mathfrak{Z}_2$ of the current transformer. It follows that the quantity FK is dependent upon the value and phase of the current J_{m_2}, that is to say, that, with a constant phase angle θ and a variable load, the point F moves along the straight line, op. This straight line forms, with the straight line, mn, an angle $\left(\frac{\pi}{2}+\varphi_a\right)$. On the other hand, if the secondary current remains constant and the angle θ varies, the point F moves along the circle K or K′. In view of this, not only is the quantity J'_{am} determined, both in value and phase, but the quantity J'_{an} too. We have still to add to these, in phase with them, the constant components $J''_{am} = J''_{an}$; we then obtain the total disturbance current ΔJ = AI from the actual magnetising characteristic. If we describe an arc with F as centre and

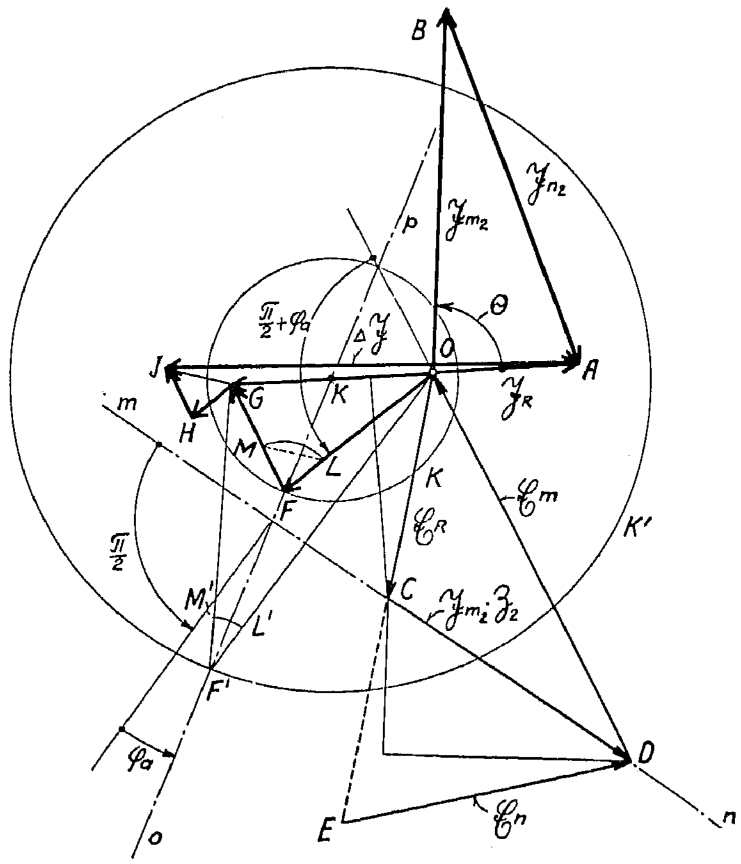


Fig. 4. Simplified method of determining the disturbance current.

FM = $J''_{am} = J''_{an}$ as radius, and connect the points of intersection L and M together, we obtain by displacing the length LM in a parallel direction, the additional current GI and, consequently, the disturbance current ΔJ = AI. The whole working characteristic can, in this way, be determined without great difficulty.

If we consider once more our working diagram, we find that, in the range AB, the quantity GI is maximum for no-load conditions and, consequently, the disturbance current ΔJ too. When, however, J''_{am} and J''_{an} are in opposition as regards phase, GI = 0, and ΔJ is minimum. As can thus be seen, the largest possible variation of the disturbance current ΔJ that can be encountered in the range of operation considered, depends upon the constant component J''_a of the magnetising current. The quantity ΔJ is minimum when the current transformers work in the range of maximum permeability; this also fixes the factor of safety for the arrangement in question.

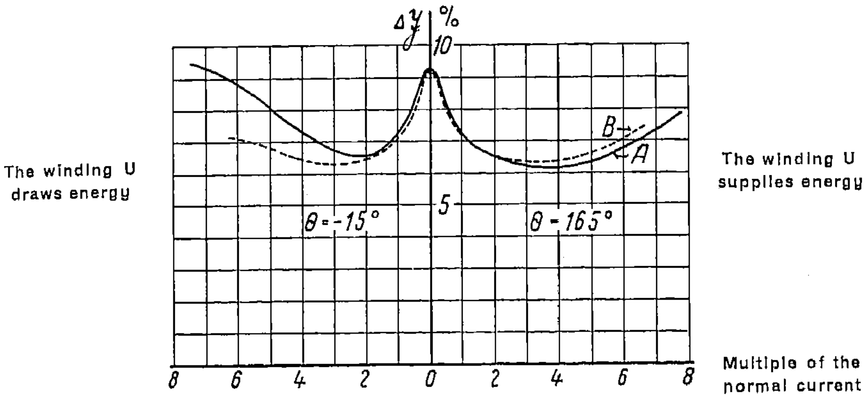


Fig. 5. Curve showing the relation between the disturbance current and the load. Constant relay current = 0.2 amp.

The above considerations lead to this important conclusion that it is essential to take into account the magnetising curve of the current transformers when planning the differential protection system, as in spite of identical characteristics, faulty releases can take place under overload conditions.

In order to illustrate the mode of operation of the differential protection, we shall consider the concrete example of a differential protection equipment, consisting of two identical current transformers for 6000 volts, 10/5 amps, 50 cycles and of a sensitive differential relay, such as designed by the Oerlikon Company for differential protection. This relay, which requires about 1 VA for its operation, is built as an instantaneously acting relay for generator protection; in the case of transformer protection, however, it is used in conjunction with a special auxiliary relay, in order to avoid undesired releases due to rushes of magnetising current which occur when switching on power transformers. The impedance of the relay amounts, in the present case, to $\mathfrak{Z}_R = r_R + jx_R = 6.8 + j\,25$ ohms, so that this relay operates for a current $I_R = \sqrt{\frac{1}{25}} = 0.20$ amp, which value has been taken into account when calculating the following curves.

We have plotted in Fig. 5, on the basis of the vector diagram in Fig. 4 and of the magnetising curve F in Fig. 3, the working characteristic A giving the relation between the disturbance current ΔJ and the secondary load current for a constant phase angle $\Theta = -15^0$ or $\Theta = 165^0$. The secondary resistance, including the external resistances has been taken as $\mathfrak{Z}_{m_2} = \mathfrak{Z}_{n_2} = 2.33 + j\,0.57$ ohms per current transformer. A first important point that can be observed from the working characteristic A is that the disturbance current ΔJ decreases from light load up to about 3 times normal load, while above this value it increases once more; on the other hand, the degree of sensitiveness increases from light load, where it has a value $\sigma_e = 11.2$, up to its maximum $\sigma_e = \frac{100}{6.3} =$ approx. 16. If, for instance, the magnetising current of the power transformer amounts to 6.7 % of the normal current, the differential relay, if set for 0.2 amp., would operate incorrectly even for a load about 1.5 times normal load; this would correspond to a factor of safety $\sigma_s = 1.5$. It thus follows that it is not possible to judge of a differential protection equipment merely by a no-load test, as the degree of sensitiveness of the equipment varies with the load. Current transformers with exactly the same characteristics are, therefore, not always sufficient for providing reliable differential protection under overload conditions.

If we compare the measured values such as plotted in curve B in Fig. 5 with the calculated values, we see that test results and calculated figures agree fairly well up to four times normal current. The method of calculation described thus provides a means whereby the mode of operation of differential protection can be investigated even under overload conditions. It is only in the case of heavy overloads that we encounter large differences between calculated figures and test results, which must be ascribed to the influence of the higher harmonics of the magnetising currents of the current transformers. This contention is actually confirmed by the oscillograms of the relay currents taken for five times normal load (Fig. 6). Table I shows the order of magnitude of the third harmonics for five times normal load, for both directions of flow of energy.

Table I.

Conditions of operation	Θ	Current curve	Sine component a_1 %	a_3 %	Cosine component b_1 %	b_3 %
The winding U of the transformer operates						
a) as a generator	− 15°	A	100	− 14.3	8.2	− 10.5
b) as a motor	165°	B	100	− 5.2	17.1	− 20.4

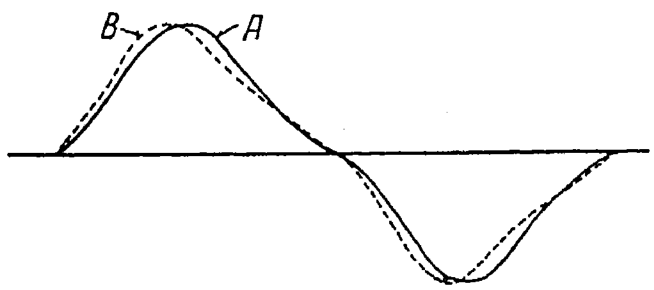


Fig. 6. Oscillogram of the relay current.

In order to eliminate the effect of the higher harmonics, which latter cannot be calculated by simple mathematical means, it is advisable to keep the saturation of the current transformers and, consequently, the secondary resistances as small as possible. In Fig. 7, we have reproduced the oscillograms of the magnetising currents of the current transformer in question for 4 different degrees of saturation; the figures arrived at for the third harmonics are given in Table II.

Table II.

Excitation pressure, volts	I_a amps., rms. value	Sine component a_1 %	a_3 %	Cosine component b_1 %	b_3 %	$\sqrt{a_3^2 + b_3^2}$ %
10	0.18	100	1.7	− 6.3	− 7.4	7.6
30	0.37	100	− 2.0	− 10.2	+ 12.2	12.2
50	0.62	100	− 7.0	− 11.8	+ 12.6	14.5
80	1.22	100	− 13.6	− 11.0	+ 12.9	18.7

This variation of the degree of sensitiveness with the load and the disturbing influence of the higher harmonics can be eliminated, in the greater part, by giving the no-load reactance of the current transformers a value as far as possible independent of the saturation — a result attained by providing a small air gap in the core of the current transformers. Owing to the lower no-load reactance, the degree of sensitiveness of the protection is, it is true, reduced, but on the other hand, a great advantage is gained in that it remains constant over a large range of overload, which means a higher factor of safety. Furthermore, the degree of sensitiveness can be raised,

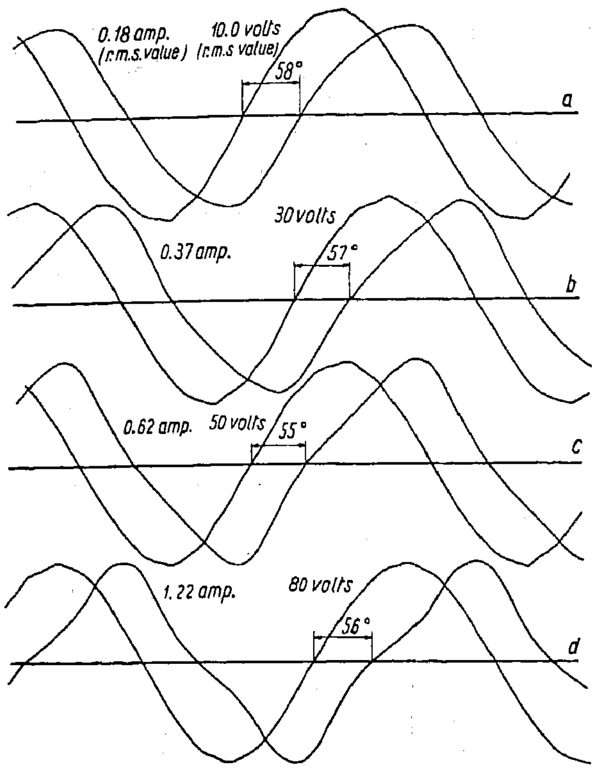


Fig. 7. Magnetising current of current transformer for different degrees of saturation.

in spite of this, to its original value by choosing the relay winding correctly, and by using highly sensitive relays; this can, in fact, be done all the better as faulty releases are not to be expected. We thus obtain a sensitive protection against faults, even under overload conditions.

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3) Relation between the degree of sensitiveness and the characteristics of the current transformers. The equation (4) and the vector diagrams in Figs. 2a and 2b show us definitely that the disturbance current ΔJ, and, consequently, the degree of sensitiveness, depend upon the relay current and upon the magnetising currents of the current transformers. The value of current for which the relay operates can be reduced, without any difficulty, in the case of a relay of given capacity, by increasing the number of turns of the magnet coil. This may not, however, always lead to a higher degree of sensitiveness of the differential protection as the magnetising currents of the current transformers increase, owing to the higher impedance of the relay. There must, therefore, be a certain ratio between the impedance of the relay and the no-load reactance of the current transformers, for which the degree of sensitiveness is maximum.

For the sake of simplicity, we shall assume that the no-load impedance of the current transformers is constant; it is given by the expression $\mathfrak{Z}_a = r_a + jx_a$. We can, therefore, write the two following equations:—

$$(J_{m1} + J_{m2})\,\mathfrak{Z}_a + J_{m2}\,\mathfrak{Z}_2 + J_R\,\mathfrak{Z}_R = 0$$

$$(J_{n1} + J_{n2})\,\mathfrak{Z}_a + J_{n2}\,\mathfrak{Z}_2 + J_R\,\mathfrak{Z}_R = 0$$

The relay current is then arrived at by adding these two equations together:

$$J_R = -\frac{\mathfrak{Z}_a}{\mathfrak{Z}_a + \mathfrak{Z}_2 + 2\,\mathfrak{Z}_R} \times \Delta J$$

If we leave out of account the ohmic resistance as being negligible as compared with the reactances and also the quantity $\mathfrak{Z}_2$, we obtain as value for the relay current, in the case of a given disturbance current ΔI:

$$I_R = \frac{x_a}{x_a + 2x_R} \times \Delta I$$

This enables us to determine the VA input required for the operation of the relay:

$$VA = I_R^2\,x_R = \frac{x_a^2\,x_R}{(x_a + 2x_R)^2} \times \Delta I^2$$

This VA input is maximum for a given size of current transformer when $x_R = \frac{x_a}{2}$ and $I_R = \frac{1}{2}\,\Delta I$.

If we revert to the equation (4), we see that the highest degree of sensitiveness is obtained when the relay current is equal to the sum of the magnetising currents of the current transformers. The above equations show once more that the relay current is independent of the load in the case of current transformers with constant permeability. According to the magnetising curve F in Fig. 3, the current transformers in our example reach the highest permeability for a pressure of about 42 volts, so that $x_a = \frac{42}{0.5} = 84$ ohms. With a given relay capacity of 1 VA, a relay reactance of 25 ohms and a relay current of 0.2 amp, we have, according to the above equation, a disturbance current $\Delta I = \frac{84 + 50}{84} \times 0.2 = 0.318$ amp. This corresponds to a current of $2 \times 0.318 = 0.636$ amp on the primary side of the current transformer, or 6.36 %, while the lowest reading obtained was 6.2 %. The degree of sensitiveness for the arrangement in question is thus $\sigma = 16$, at the most.

In order that there should be no faulty releases, in the case of transformer protection, under overload conditions, it is necessary to set the relay high enough to ensure that the minimum value of the disturbance current is above the maximum possible value of the magnetising current of the power transformer.

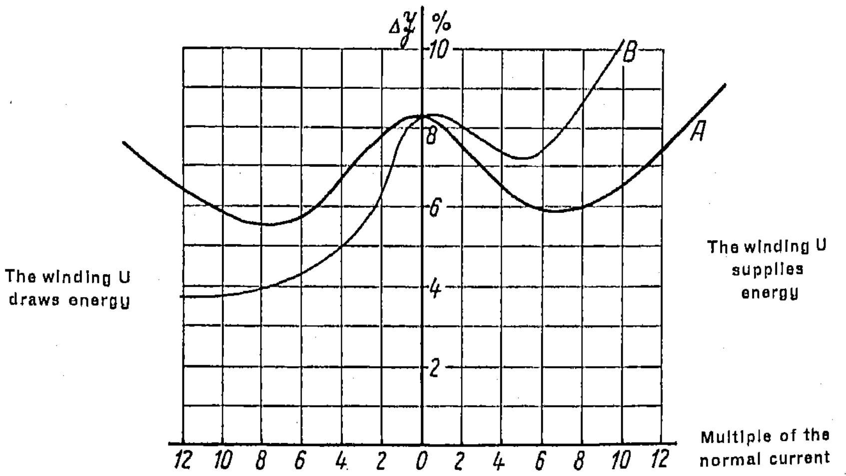


Fig. 8. Disturbance current for different loads, in the case of current transformers with the same magnetising curves.
Curve A: $\mathfrak{Z}_{2m} = \mathfrak{Z}_{2n} = (0.35 + j\,0.57)$ ohms
Curve B: $\mathfrak{Z}_{2m} = (0.35 + j\,0.57)$ ohms; $\mathfrak{Z}_{2n} = (0.55 + j\,0.57)$ ohms

4) Mode of operation of the differential protection when dissimilar current transformers are used. Current transformers for very high pressures have, as a rule, a considerably higher secondary resistance than those for lower pressures. The no-load reactance is, however, on the other hand, smaller

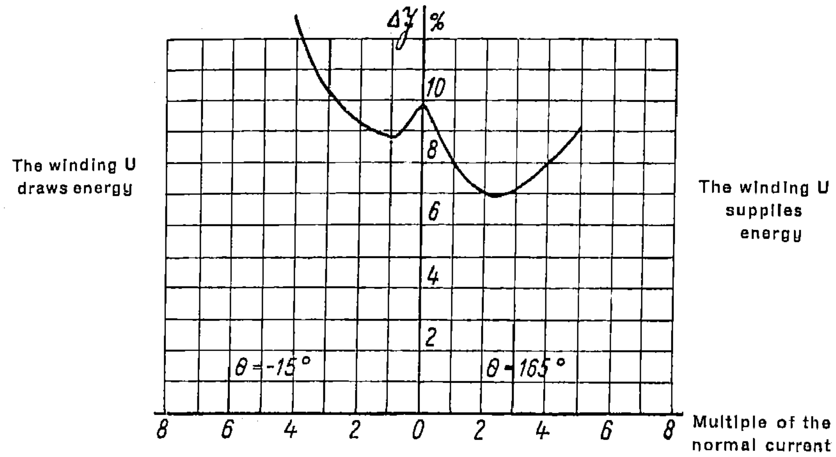


Fig. 9. Disturbance current for different loads, in the case of current transformers with different magnetising curves. Constant relay current = 0.2 amp., 50 cycles.

for the current transformers on the high tension side than for those on the low tension side. This is the case more especially for bushing or single-conductor current transformers such as often used in high tension systems. If, therefore, great importance is attached to having a differential protection equipment which is reliable over as large a range of overload as possible, that is to say, which operates without danger of faulty releases, it is absolutely necessary to take into account these differences. The differences in the secondary resistances can be compensated in a relatively simple way, by providing additional resistances and reactances. It is often possible to use existing overload relays for this purpose, provided their impedance does not change with the position of the core and the load. In Fig. 8, we have plotted a curve showing how the disturbance current varies in function of the load, when the secondary resistance of one branch of the differential circuit is about 20% higher than that of the neighbouring branch. We also give a curve A corresponding to the same conditions of operation, for the case where the secondary resistances are identical. It will be noticed, in particular, that when the secondary resistances are different, the working characteristic no longer occupies a symmetrical position in relation to the axis of ordinates. The differential protection has not, therefore, the same degree of sensitiveness in the case of the same load for both directions of flow of energy. For one direction of flow, the degree of sensitiveness is higher, so that undesired releases may result, while for the other direction of flow, it is reduced to an excessive degree. The disturbance current varies in a similar way, when the two current transformers have different magnetising characteristics. The curve for ΔJ can then be determined by means of the vector diagram in Fig. 2a, on the basis of the two magnetising characteristics in question. Fig. 9 shows, for instance, the working characteristic determined on the basis of the magnetising curves E and F in Fig. 3; in this connection, we have taken the same resistances for the relays and current transformers as in the case of the curves in Fig. 5. The differences in the magnetising curves and the harmful effect they have on the factor of safety can only be eliminated by properly dimensioning the core of the current transformers and choosing the number of turns in such a way as to make the magnetising curves agree better. It is then possible to determine, by calculation, over what range the differential equipment can still work satisfactorily. In many cases, it is also possible to compensate the differences in the magnetising currents, to a certain extent, by making use of auxiliary current transformers.

5) Effect of deviations from the correct transformation ratio of current transformers. There is no difficulty in equalising the transformation ratio of current transformers in the case of generator protection, as both current transformers have exactly the same number of turns. In the case of transformer protection, however, the transformation ratio of the current transformers has to be adjusted to the transformation ratio of the power transformer protected. If we designate the transformation ratio of the current transformer M by $U_m = \frac{W_{m_2}}{W_{m_1}}$, the transformation ratio of the current transformer N by $U_n = \frac{W_{n_2}}{W_{n_1}}$ and, finally, the transformation ratio of the power transformer by $U_T = \frac{W_o}{W_u}$, and we assume that the mode of connection of the latter is the same on the primary and on the secondary side, the following condition must be satisfied, in order that no current should flow through the differential relay when the service is undisturbed:— $\frac{U_m}{U_n} = \frac{W_o}{W_u} = \frac{W_{m_2}}{W_{m_1}} \times \frac{W_{n_1}}{W_{n_2}}$

Transformers in distribution systems are very often provided with several tappings on the low or high tension side, in order to regulate the supply of power of the transformers. As, however, the transformation ratio of the current transformers has to remain in inverse proportion to the number of turns of the corresponding transformer windings, it is necessary also to provide the current transformers with the same number of tappings. The provision of such tappings undoubtedly means a considerable complication of the differential protection. Apart from this, it is fairly certain that the maintenance staff would, in most cases, forget to make the necessary changes in connection, should this changing over not be done automatically by means of special devices. The question is, therefore, under what conditions and over what range is it still permissible to dispense with complete adjustment of the transformation ratio, without this causing a too great reduction in the degree of sensitiveness or in the factor of safety. With a view to studying more in detail the effect of an incomplete adjustment, we shall assume, for the sake of simplicity, that the permeability of the current transformers is constant and we shall designate by $\mathfrak{Z}_a$ the constant vector of the excitation impedance of both current transformers. The ratio between turns, in the case of the power transformer as well as of the current transformer M, will be set down as unity while, in the case of the current transformer N, it will be taken as $U_n = \frac{W_{n_2}}{W_{n_1}} = \frac{1}{1+\Delta U}$ = approx. $1-\Delta U$; this means that we disturb the ratio of the current transformer N to the extent of $\Delta U \times 100\,\%$.

In view of the fact that we refer all quantities to the secondary circuit of the current transformers, we have the following equations: —

$$+(J_{m_1}+J_{m_2})\,\mathfrak{Z}_a + J_R\,\mathfrak{Z}_R + J_{m_2}\,\mathfrak{Z}_2 = 0$$

$$+(J_{n_1}[1+\Delta U]+J_{n_2})\,\mathfrak{Z}_a + J_R\,\mathfrak{Z}_R + J_{n_2}\,\mathfrak{Z}_2 = 0.$$ This gives us:

$$+\Delta J\,\mathfrak{Z}_a + \Delta U\,J_{n_1}\,\mathfrak{Z}_a + J_R\,(\mathfrak{Z}_a + \mathfrak{Z}_2 + 2\,\mathfrak{Z}_R) = 0$$

The resulting relay current corresponding to the disturbance current $\Delta J = 0$ is given by the following expression: —

$$J_R = -\frac{\Delta U\,J_{n_1}\,\mathfrak{Z}_a}{\mathfrak{Z}_a + \mathfrak{Z}_2 + 2\,\mathfrak{Z}_R}$$

This means that, if we neglect the ohmic resistances, the value of the relay current is $I_R = \frac{\Delta U\,I_{n_1}\,x_a}{x_a + x_2 + 2x_R}$.

If we alter, in the above example, the transformation ratio of one of the current transformers to the extent of 4.2%, we

obtain as value of relay current for a normal load current $I_{n1} = 5.0$ amps and $x_a = 84$ ohms, in the case of a disturbance current $\Delta I = 0$:

$$I_R = \frac{0.042 \times 5 \times 84}{84 + 0.57 + 50} = 0.132 \text{ amp.}$$

Under these conditions, the relay would, therefore, bring about a faulty release even for an overload factor $\sigma_s = \frac{0.20}{0.132} = 1.52$; consequently, the relay would have to be set for a considerably higher value. During tests, the relay came into play at 1.6 times normal load, for $\Delta I = 0$. As, however, there is always, in the case of transformer protection, a certain disturbance current $\Delta J = J_a$ corresponding to the no-load current of the transformer, referred to the secondary circuit of the current transformers, the relay current is, according to the above given equation by the expression:—

$$J_R = -(J_a + \Delta U J_{n1}) \frac{\mathfrak{Z}_a}{\mathfrak{Z}_a + \mathfrak{Z}_2 + 2\,\mathfrak{Z}_R}$$

The conditions are most unfavourable when J_a is in phase with J_{n1}; the relay current then reaches its maximum value. On the other hand, it may also occur that the relay current is reduced in the event of a disturbance, when the currents ΔJ and $\Delta U\, J_{n1}$ are in opposition, with the result that the relay only comes into play for a relatively high disturbance current. The question as to whether a certain equalisation of the fault in transmission ratio is permissible or not, is a matter which has always to be investigated as the case arises; when doing so, it is necessary to take into account the range of operation of the power transformer. In the case of transformers which serve for interconnecting two power stations, all possible conditions of service can be encountered; it is then necessary to introduce as value for $(J_a + \Delta U\, J_{n1})$ that corresponding to the most unfavourable conditions, where J_a and $\Delta U\, J_{n1}$ are in phase or in opposition.

Protection of Transformers working in conjunction with Induction Regulators. The most effective way of regulating the wattless output of power stations is by means of induction regulators in which case this plant works, as a rule, on the distribution system through the intermediary of transformers, owing to the high transmission pressures. The provision of large installations for the regulation of the wattless KVA. has led to the adoption, in such cases too, of the Merz-Price method of protection for the transformers, the protection of the induction regulators being confined to ordinary overload protection with overload time relays. There is this special advantage about differential protection that it is possible to include within its range of protection, other parts of the installation too, so that the high cost of such a mode of protection is all the more justified. Such considerations lead, quite naturally, in the case of induction regulator installations, in particular, to the idea of grouping induction regulators and transformers within the same scheme of protection, so that, for instance, in the event of a short-circuit in the induction regulator, this should cause the operation of the differential protection. Such an arrangement is, however, not possible without the provision of special auxiliary means or without a too great reduction in the degree of sensitiveness, as during the regulation process the transformation ratio of the whole regulating equipment consisting of induction regulator and transformer would alter too much. In other words, the rotor current varying as it does with the load and the position of rotor would, in certain cases, cause undesired releases by the differential relay, as a result of the incomplete adjustment of the current transformers.

It has, therefore, been necessary in order to overcome this difficulty to devise some means of compensating the effect of the rotor current; this result can be achieved either by introducing in the circuit of the differential relay a current proportional to the rotor current, or by providing the differential relay with a kind of compensation winding, through which the rotor current flows and which counteracts the disturbing effect of the latter. The first method is shown in the diagram in Fig. 10. With the arrangement in question the secondary winding of the current transformer in the rotor circuit is connected to the secondary windings of the two current transformers M and N in such a way that, under normal conditions of service, no current flows through the differential relay apart from the magnetising current of the transformer; in this case, the transformation ratio of the current transformer in the rotor circuit has to be the same as for the current transformer N on the stator side, in order that the current transformer in the rotor circuit should only carry a relatively small load during normal service. In the case of the second arrangement with compensation winding, any transformation ratio can be taken for the current transformer in the rotor circuit, as long as it suits the maximum current relay provided in the rotor circuit. Fig. 11 shows the arrangement for differential protection such as used for an induction regulator installation equipped with compensated differential relay.

As shown in the preceding section, the relay current increases in the same ratio as the load, when the transformation ratios of the current transformers are incompletely adjusted, and causes, even in the case of small overload, undesired releases by the differential protection equipment. In order to prevent this, it is necessary to eliminate the effect of the differential current produced by the rotor current, by choosing the number of compensation turns accordingly.

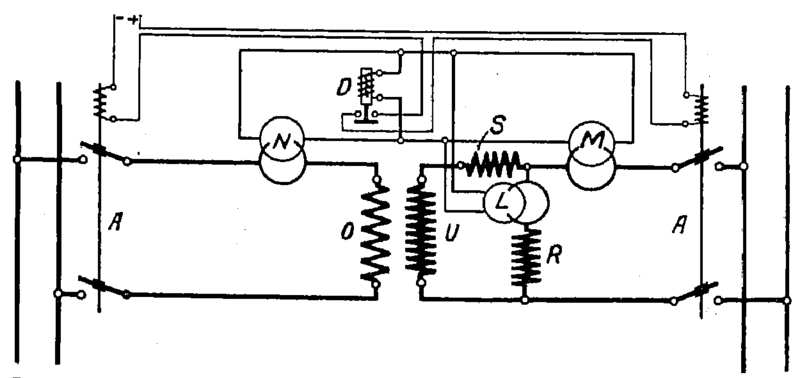


Fig. 10. Induction regulator equipment with differential protection.

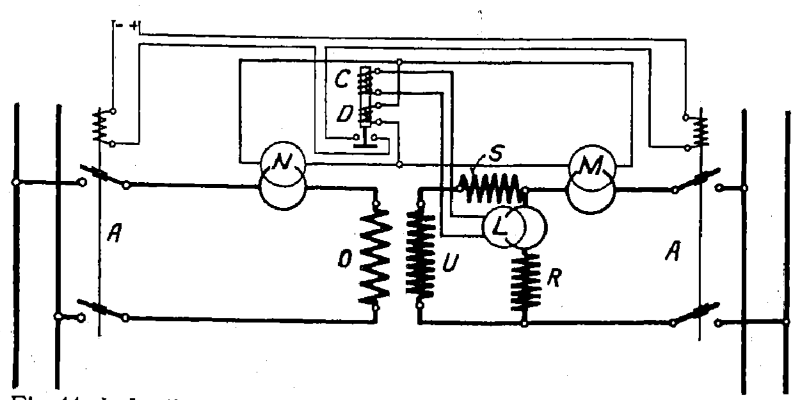


Fig. 11. Induction regulator equipment with differential protection (compensated relay).

ATELIERS DE CONSTRUCTION OERLIKON, OERLIKON

BULLETIN OERLIKON

No. 113 — November 1930

Contents: Stresses due to heavy currents in circuit breakers.

Notes and News Items: 110-ton travelling crane. — Luffing jib cranes.

Three-phase four-winding transformers for the Ryburg-Schwœrstadt Power Supply Co. of Rheinfelden, Switzerland.

Stresses due to heavy currents in circuit breakers.

As a result of the continual increase in capacity of power stations, new phenomena due to the heavy currents to be dealt with have had to be faced. In the case of heavy short-circuit currents, the electro-dynamic forces exerted by the various parts of a circuit upon each other assume, in fact, very considerable values. A phenomenon which is specially well-known and dreaded is the so-called contact lifting effect in circuit breakers. It may happen that the forces that come into play are so great that the contacts are raised or that the cross-arm is even prevented from fully closing. The consequences of this contact raising effect are the following:—

a. Production of an arc accompanied by heavy local heating. This causes the melting and even the welding of the neighbouring contacts. The circuit breaker "sticks" i. e. the cross-arm can no longer move.

b. The work developed by the arc causes the production of gases and gives rise to pressure impacts with the same accompanying phenomena as when switching off large outputs.

We propose to deal in the present study with the calculation of the electro-dynamic forces, in the case of a single-conductor arrangement, such as encountered in circuit breakers.

The values of these forces can be calculated in two different ways:—

1) Calculation based upon the alteration in the magnetic field energy.

If sections of conductors in a circuit are displaced while the current remains constant, an alteration of the magnetic field takes place. The force is obtained by differentiating the magnetic energy in the direction of the force in question.

The manner in which these calculations are carried out is described in the book of Dr. Roth [1]).

In the case of a current loop (Fig. 1) such as encountered nearly exclusively in circuit breakers, the total lifting force K acting on the cross-arm is given by the expression:—

$$K = K_i + K_a = \frac{2\,i^2}{9.81 \times 10^7} \times \left[\frac{1}{4} + \ln \frac{(a_1 - r_1)}{r_1}\right] \qquad (1)$$

K in kgs. i in amps. a_1 and r_1 in cms.
ln natural logarithm.
K_a force due to the flux outside the conductor.
K_i force due to the flux inside the conductor.

In this connection, we have assumed that the length l of the supply conductors is very great. If a_1 is great as compared with r_1, we have further:—

$$K = \frac{2\,i^2}{9.81 \times 10^7}\left[\frac{1}{4} + \ln \frac{a_1}{r_1}\right]$$

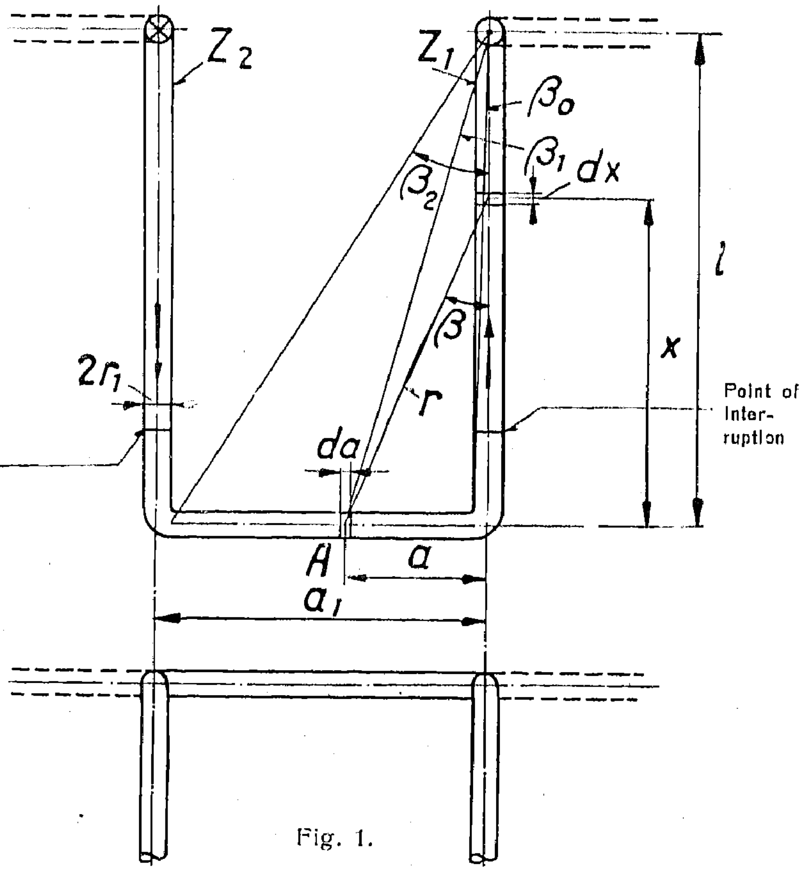


Fig. 1.

The points of application of these forces are distributed on the parts which are perpendicular to the direction of the supply conductors Z_1 and Z_2, that is to say, in the case of

[1]) "Hochspannungstechnik" by Dr. (Eng.) Arnold Roth, pages 411 and following.

circuit breakers, on the cross-arm. The formula gives, however, no information with regard to the distribution of the forces along the latter. The cross-arm can, in fact, have any desired shape without this affecting the lifting force. Furthermore, we see that it is always the radius at the point of interruption itself which is the determining factor for the calculation of the lifting force K for r_1, while the component K_i does not depend upon the contact radius r_1.

II) Calculation of the electro-dynamic forces by means of the formulae of Biot-Savart and Laplace.

Although these formulae have no physical justification as they refer to current elements and the latter do not exist independently in practice, the use of these formulae presents, in many cases, decided advantages as compared with the mode of calculation based on the magnetic field energy.

The formula of Laplace permits of the calculation of the component of the magnetic field due to a conductor element, at a desired point in the neighbourhood of the conductor.

If we designate by dH_A, the component of the magnetic field due to the conductor element dl, at the point A in Fig. 2, we have the following formula:—

$$dH_A = \frac{i \times dl \times \sin \vartheta}{10\, r^2} \qquad (2)$$

where i = current in the conductor element, in amps.
r = distance of the conductor element from the point A, in cm.
H_A = field at the point A, in gauss.
ϑ = angle between the straight line r and the conductor element dl.

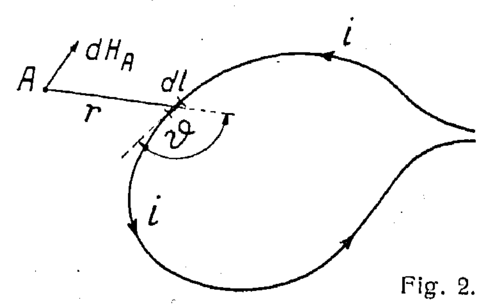


Fig. 2.

The formula itself only gives the absolute value of the component. The direction is fixed by the cork-screw rule and also by the condition that the field at the point A is perpendicular to the plane formed by the straight line r and the conductor element dl. The total field created by the whole circuit at the point A is obtained by integration along the whole conductor.

1) Calculation of the lifting forces acting on the cross-arm in circuit breakers. Let us consider a current loop as shown in Fig. 1. We can first calculate the field and, in this connection, we shall assume that the whole current is concentrated in the centre line of the current conductor.

The field H_A at the point A, due to the supply conductor Z_1 with a length l, is obtained by means of the following formula:—

$$H_A = \frac{i}{10}\int_0^l \frac{dx \times \sin\beta}{r^2} \quad \text{or} \quad H_A = \frac{i \times \cos\beta_1}{10\,a} = \frac{i}{10\,a} \times \frac{1}{\sqrt{a^2 + l^2}}$$

On the other hand, it is possible to calculate, by means of the formula of Biot-Savart the force dK_A, exerted by the field H_A on the current element of length da. The general formula is as follows:—

$$dK_A = \frac{i \times da}{9.81 \times 10^6}\, B_A \times \sin\gamma$$

γ = angle between the current element $i \times da$ and the vector B_A.

The force dK_A is perpendicular to the plane formed by the conductor element da and the vector B_A. The direction of the force is obtained by means of the so-called hand or corks-screw rule. In our particular case, $\gamma = 90^0$ and we thus have:—

$$dK_A = \frac{i^2 \times \cos\beta_1 \times da}{9.81 \times 10^7 \times a} = \frac{i^2 \times l \times da}{9.81 \times 10^7 \times a \times \sqrt{a^2 + l^2}} \qquad (3)$$

K_A in kgs. i in amps. a und l in cms.

If we integrate this expression in respect of a, between the limits r_1 and $(a_1 - r_1)$, and in respect of β_1 between the limits β_0 and β_2, we obtain the expression:—

$$K_A = \frac{i^2}{9.81 \times 10^7} \times \ln \frac{tg\left(\frac{\beta_2}{2}\right)}{tg\left(\frac{\beta_0}{2}\right)} = \frac{i^2}{9.81 \times 10^7} \times \ln \frac{(a_1 - r_1)\,(1 + \sqrt{r_1^2 + l^2})}{r_1\,(1 + \sqrt{(a_1 - r_1)^2 + l^2})} \qquad (4)$$

The force exerted by the supply conductor Z_2 on the cross-arm is the same as for Z_1; the component K_i is, according to formula (1): $\frac{2\,i^2}{9.81 \times 10^7} \times \frac{1}{4}$. The total lifting force acting on the cross-arm for a limited length l of the supply conductors, is thus given by the expression:—

$$K = \frac{2\,i^2}{9.81 \times 10^7}\left[\frac{1}{4} + \ln \frac{(a_1 - r_1)\,(1 + \sqrt{r_1^2 + l^2})}{r_1 \times (1 + \sqrt{(a_1 - r_1)^2 + l^2})}\right] \qquad (5)$$

If l is very large as compared with a_1 and r_1, the formulae (5) and (1) agree.

The accuracy of these calculations was checked by means of tests. In Fig. 3, we have plotted the value of the lifting force for a distance between contacts $a_1 = 16$ cm and a ra-

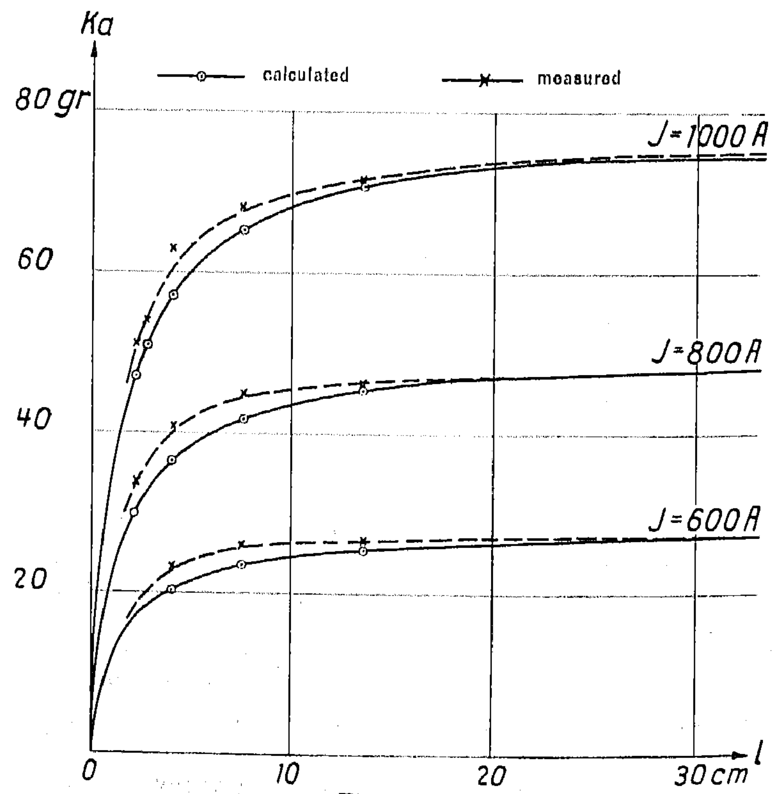


Fig. 3.

dius of contacts $r_1 = 0.5$ cm, in function of the length l of the supply conductors. Measurements and calculations can be said to agree very well. If we calculate the lifting force for a circuit breaker with $l = 40$ cm, $a_1 = 25$ cm and $r_1 = 0.15$ cm, it is only about 9 % smaller as compared with the value for the length l = infinity.

If the supply conductors are extended in the case of the same circuit breaker, in the horizontal direction, along the dotted line as shown in Fig. 1 and assumed to have a length infinity, there would be a further reduction of the lifting force of only about 9 %.

From the above, it may be concluded that in the case of standard oil circuit breakers, the lifting force acting on the cross-arm, is not affected to a very considerable extent by the manner in which the supply conductors are arranged. When l is very large as compared with a, we have, according to the equation (3):

$$dK_A = \frac{i^2 \times da}{9.81 \times 10^7 \times a}$$

The mode of distribution of the lifting force due to Z_1 over the contact cross-arm, would thus correspond to a hyperbola. In Fig. 4, the curve 1 shows the mode of distribution of the force due to Z_1, while the curve 3 gives the mode of distribution of the total force.

If the contact radius is drawn correctly to scale, the shaded area represents the lifting force exerted by Z_1. The

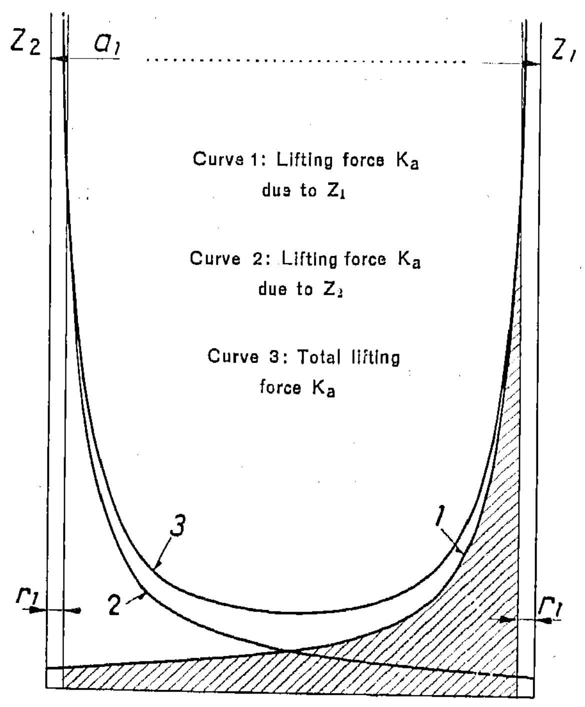


Fig. 4.

same applies to the total lifting force, curve 3. The alteration in area due to different contact diameters thus represents the alteration in the lifting force. A point which is specially clear is the influence of small contact diameters.

2) Calculation of the forces in the case of several current loops. The foregoing calculations referred to a single, simple current loop. In the case of triple-pole circuit breakers, the individual circuits of the three phases act upon each other, so that the phase of the current has to be taken into account. The total forces acting on the cross-arm of circuit breaker are, for the case where the latter is rigidly connected to the contact cross-arms, equal to the sum of the three forces acting upon the contact cross-arms. We now propose to calculate this force, and, in this connection, we shall first leave out of consideration the mutual action of the three phases and then take it into account.

2a) Calculation leaving out of consideration the mutual action of the three phases. According to formula (1), the force exerted by a single current loop is:—

$$K = \frac{2 i^2}{9.81 \times 10^7} \left[\frac{1}{4} + \ln \frac{(a_1 - r_1)}{r_1} \right]$$

If we take three-phase current and a symmetrical load, the values to be introduced for i are as follows:—

$i_1 = I_{max} \times \sin \omega t$, $i_2 = I_{max} \times \sin(\omega t - 120^\circ)$, $i_3 = I_{max} \times \sin(\omega t - 240^\circ)$

The total lifting force acting on the cross-arm of circuit breaker is the sum of the three forces exerted on the contact cross-arms:

$$K_{tot} = K_{11} + K_{22} + K_{33} = \frac{3 I_{max}^2}{9.81 \times 10^7} \left[\frac{1}{4} + \ln \frac{(a_1 - r_1)}{r_1} \right] \quad (6)$$

I_{max} = amplitude of the current.

The force acting on the cross-arm of circuit breaker is thus constant and 1.5 times larger than the maximum force exerted on a single contact cross-arm. The curves K_{11}, K_{22}, K_{33} in Fig. 5 represent the mode of variation, in time, of the forces of the individual contact cross-arms.

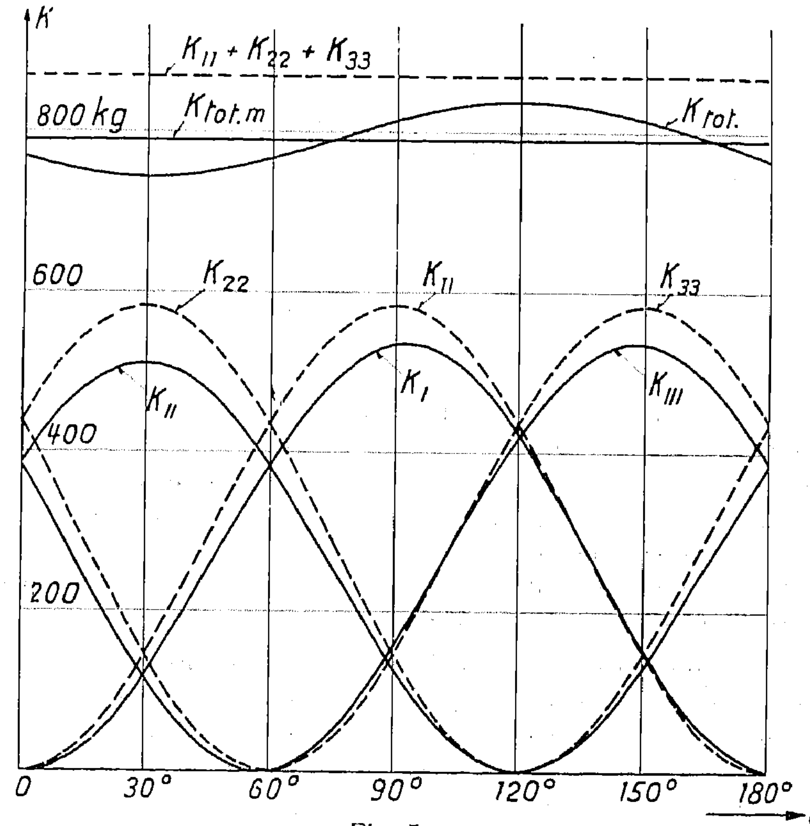


Fig. 5.

K_I = Lifting force of phase I $\quad$ K_{III} = Lifting force of phase III
K_{II} = " " " " II $\quad$ $K_{tot} = K_I + K_{II} + K_{III}$

The dotted curves represent the lifting force for the case where the mutual action is left out of account.

2b) Calculation taking into account the mutual action of the phases. Fig. 6 represents a triple-pole circuit breaker diagrammatically; the length l is taken as very great. We can calculate in the same simple way, as described on page 566, the components of the magnetic field of the three

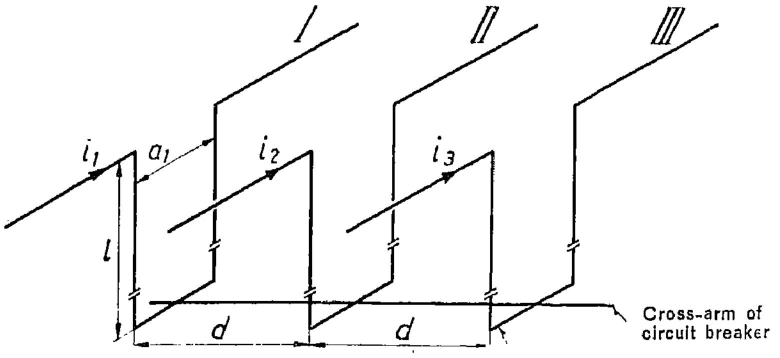


Fig. 6.

phases for a desired point of the contact cross-arm. If we designate by K_I, K_{II} and K_{III}, the forces acting on the contact cross-arms of the different phases, we have:—

$$K_I = \frac{2i_1}{9.81\times10^7}\left[i_1\left(\frac{1}{4}+\ln\frac{a_1}{r_1}\right)+i_2\times\ln\frac{\sqrt{a_1^2+d^2}}{d}+i_3\times\ln\frac{\sqrt{a_1^2+4d^2}}{2d}\right]$$

$$K_{II} = \frac{2i_2}{9.81\times10^7}\left[i_1\times\ln\frac{\sqrt{a_1^2+d^2}}{d}+i_2\left(\frac{1}{4}+\ln\frac{a_1}{r_1}\right)+i_3\times\ln\frac{\sqrt{a_1^2+d^2}}{d}\right]$$

$$K_{III} = \frac{2i_3}{9.81\times10^7}\left[i_1\times\ln\frac{\sqrt{a_1^2+4d^2}}{2d}+i_2\times\ln\frac{\sqrt{a_1^2+d^2}}{d}+i_3\left(\frac{1}{4}+\ln\frac{a_1}{r_1}\right)\right]$$

The total lifting force K_{tot} is the sum $K_I + K_{II} + K_{III} = K_{tot}$. If we adopt the following abbreviations:—

$$\left(\frac{1}{4}+\ln\frac{a_1}{r_1}\right) = k_1 \quad \text{and} \quad i_1 = I_{max}\times\sin\omega t$$

$$\ln\frac{\sqrt{a_1^2+d^2}}{d} = k_2 \quad\quad i_2 = I_{max}\times\sin(\omega t-120^0)$$

$$\ln\frac{\sqrt{a_1^2+4d^2}}{2d} = k_3 \quad\quad i_3 = I_{max}\times\sin(\omega t-240^0)$$

we obtain by simplification, the following expression:—

$$K_{tot} = \frac{I^2_{max}}{9.81\times10^7}\left[3k_1-2k_2-k_3+(k_3-k_2)\,(\cos 2\omega t+\sqrt{3}\times\sin 2\omega t)\right] \quad (7)$$

The total force that tends to raise the cross-arm of circuit breaker has twice the frequency of the current. In Fig. 5, we have plotted the instantaneous values K_I, K_{II}, K_{III}, as well as K_{tot} in function of the time. The maximum value of the force acting on the middle contact cross-arm is smaller than that applied to the two outer phases. It can further be seen that, if we take into account the mutual action of the three phases, the maximum lifting force for the case dealt with is about 5 % smaller than when the mutual action is left out of account. As can further be seen from Fig. 5, a torque is applied to the cross-arm of circuit breaker in respect of the centre of the latter; in other words, the point of application of the force K_{tot} moves to and fro on the cross-arm of circuit breaker. It is only for $\omega t = 30^0$, $\omega t = 120^0$, and $\omega t = 300^0$ that the point of application is in the centre of the cross-arm.

3) Calculation of the lifting forces in the case of sliding contacts. Sliding contacts differ essentially from block contacts in that the motion of the circuit breaker is parallel to the contact surface, while with block contacts the displacement is in a perpendicular direction.

In the case of all these arrangements, two kinds of forces have to be taken into account:—

a) Forces which tend to drive the contact surfaces apart.
b) Forces which act on the cross-arm.

The latter forces can be calculated without difficulty by means of the formulae given in Section II. It must, however, be observed that the section to be taken as contact section is an equivalent circular surface in respect of the force. Instead of having to deal with a single point of application as with block contacts, we have in the case of finger contacts a considerably larger ideal contact diameter; this means a considerable reduction in the forces acting on the cross-arm.

In Fig. 7, we give the mean current paths in the case of a contact finger arrangement which we shall designate by A. The individual sections are indicated by the letters m, e, f, g, h, i, d, l, a, b. In this connection, we shall assume, for the time being, that the incoming and outgoing leads e, m and i, d are very long. The contact point is on the centre line of the finger. The field H_A at the point A of Fig. 7 is thus:—

$$H_A = H_{ma}+H_{ea}+H_{fa}+H_{ga}+H_{ha}+H_{ia}+H_{da}-H_{la}-H_{ba}$$

H_{ma}, H_{ea}, H_{fa}, H_{ga} represent the components of the field, at the point A, due to the sections m, e, f . . If we calculate these values of H_A with the formula of Laplace, and use the notations of Fig. 7, we arrive at the following expression:

$$H_A = \frac{i}{10}\left[\frac{2c}{w(c-w)}+\frac{\sqrt{x^2+c^2}}{x\times c}-\frac{\sqrt{x^2+w^2}}{x\times w}-\frac{\sqrt{x^2+(c-w)^2}}{x(c-w)}+\frac{\sqrt{(l_1-x)^2+c^2}}{c(l_1-x)}-\frac{\sqrt{(l_1-x)^2+(c-w)^2}}{(l_1-x)(c-w)}-\frac{\sqrt{w^2+(l_1-x)^2}}{w(l_1-x)}\right]$$

The total force K acting on the finger is obtained by means of the formula of Biot-Savart; we have:—

$$K = \int_{r_1}^{(l_1-r_1)}\frac{i}{10}\,H_A\times dx$$

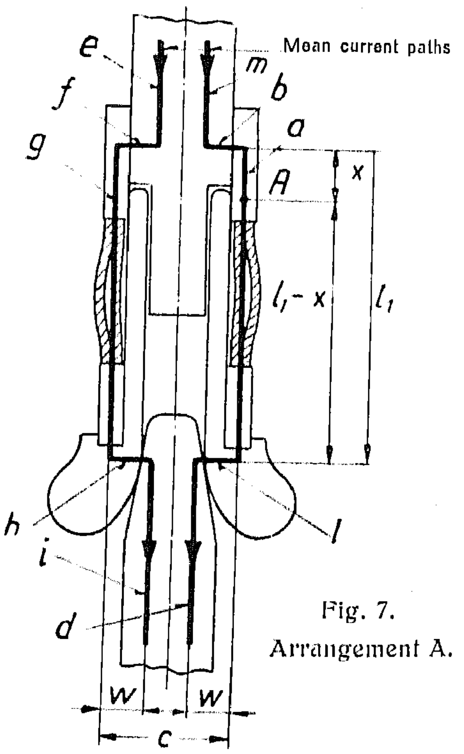


Fig. 7.
Arrangement A.

Let us adopt the following abbreviations:—

$$\sqrt{c^2+r_1^2} = A_1$$
$$\sqrt{w^2+r_1^2} = A_2$$
$$\sqrt{(c-w)^2+r_1^2} = A_3$$
$$\sqrt{c^2+(l_1-r_1)^2} = B_1$$
$$\sqrt{w^2+(l_1-r_1)^2} = B_2$$
$$\sqrt{(c-w)^2+(l_1-r_1)^2} = B_3$$

we have:—

$$K = \frac{i^2\times 2}{9.81\times10^7}\left[\frac{c(l_1-2r_1)}{w(c-w)}+\frac{B_1-A_1}{c}+\frac{A_2-B_2}{w}+\frac{A_3-B_3}{(c-w)}+\ln\frac{r_1(A_1+c)(B_2+w)(B_3+(c-w))}{(l_1-r_1)(B_1+c)(A_2+w)(A_3+(c-w))}\right] \quad (8)$$

K in kgs. i in amps. l_1, w, c, r_1 in cms.

As the whole arrangement is symmetrical, the force K is applied in the centre of the length l_1 of finger. The finger, which is kept under compression, is hinged at the upper end, so that the torque exerted on it can be calculated by means of the following formula:—

$$M = K\times\frac{l_1}{2}$$

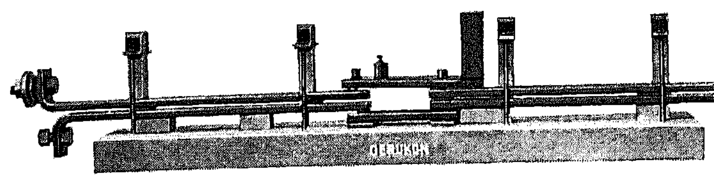


Fig. 8.

In order to be able to check these calculations by actual measurements, a model was made reproducing the supply conductors of finger contacts (Fig. 8). The model of the finger used for the measurements was carried by two knife edges. The current was led from the supply to the fingers by means of mercury contacts. In Fig. 9, we have plotted the torque for various lengths l_1 of fingers and radii r_1 of contacts, in function of the distance between fingers. The calculated and measured values can be said to agree very well.

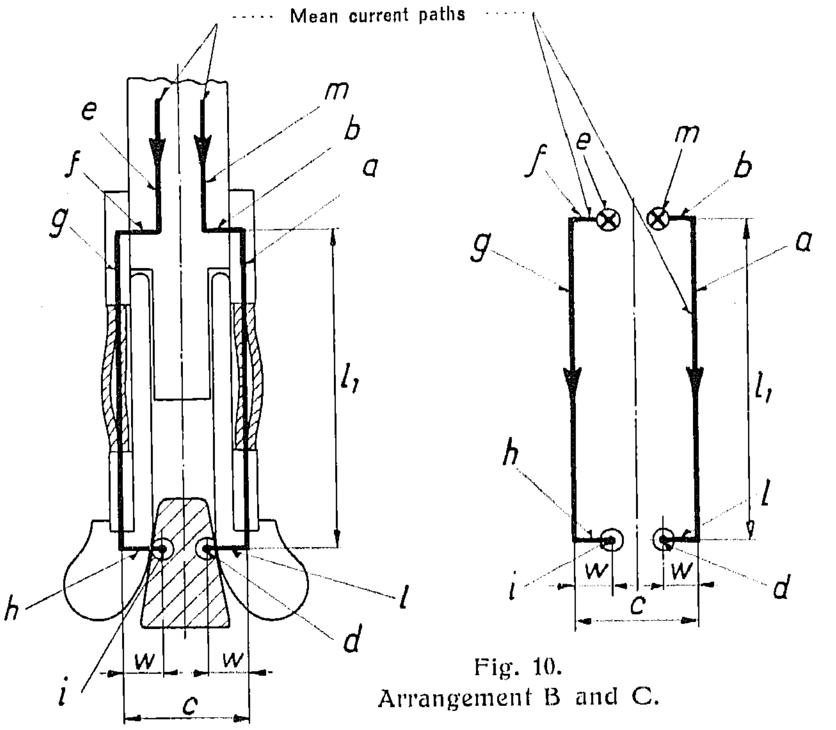


Fig. 10.
Arrangement B and C.

In order to get a better idea of the importance of the influence of the mode of leading the current to the contact fingers, the same calculations and measurements were made in the case of the arrangements B and C represented in Fig 10. The arrangement B corresponds to the usual mode of leading the current adopted at the present-day, while the arrangement C is more of theoretical interest. The torque exerted on the finger, in kg-cm, can be obtained by means of the following formula:

Arrangement B

$$M = \frac{i^2}{9.81\times10^7}\Big[\frac{l_1\times c\,(l_1-2r_1)}{2w\,(c-w)}+\frac{l_1\,(B_1-A_1)}{c}+\frac{r_1}{2}\Big(\frac{A_2}{w}+\frac{A_3}{(c-w)}\Big)$$
$$-\Big(\frac{l_1-r_1}{2}\Big)\Big(\frac{B_2}{w}+\frac{B_3}{(c-w)}\Big)+\frac{w}{2}x\ln\frac{B_2+(l_1-r_1)}{A_2+r_1}+\frac{c-w}{2}x\ln\frac{B_3+(l_1-r_1)}{A_3+r_1}$$
$$+\,l_1\times\ln\frac{r_1\,(A_1+c)\,(B_2+w)\,(B_3+(c-w))}{(l_1-r_1)\,(B_1+c)\,(A_2+w)\,(A_3+(c-w))}\Big] \qquad (9)$$

Arrangement C

$$M = \frac{i^2\times l_1}{9.81\times10^7}\Big[\frac{B_1-A_1}{c}+\ln\frac{r_1\,(A_1+c)\,(B_2+w)\,(B_3+(c-w))}{(l_1-r_1)\,(B_1+c)\,(A_2+w)\,(A_3+(c-w))}\Big] \qquad (10)$$

M in kg-cm. i in amps. ln natural logarithm.

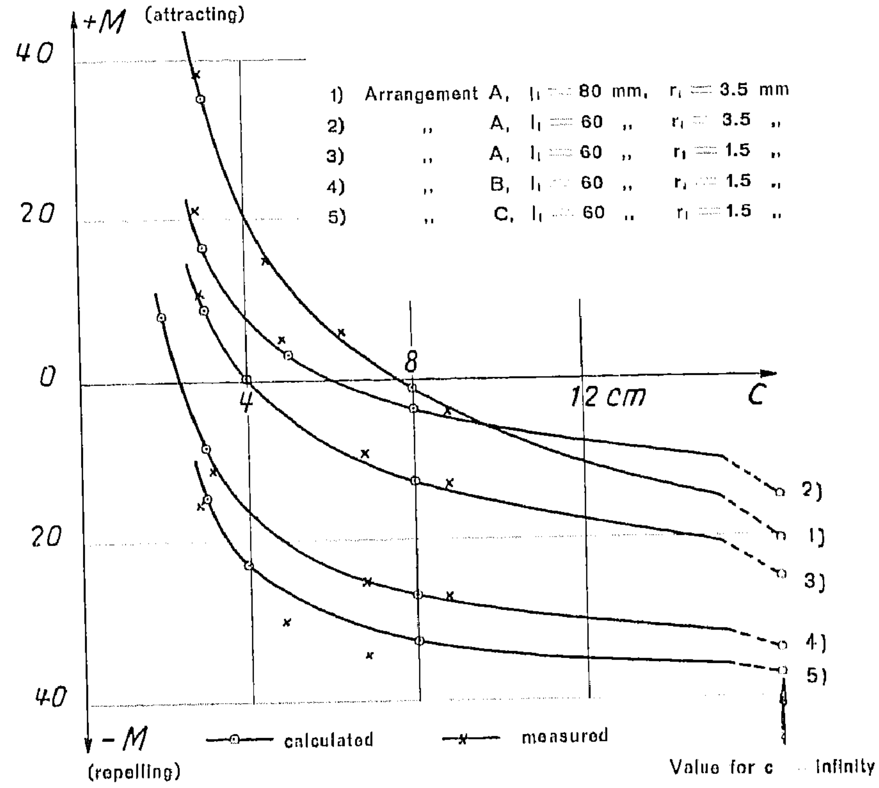


Fig. 9. Torques acting on finger contacts in function of the respective distance c, in the case of different arrangements. $I_{(\mathrm{rms\ value})}$ = 500 amps.

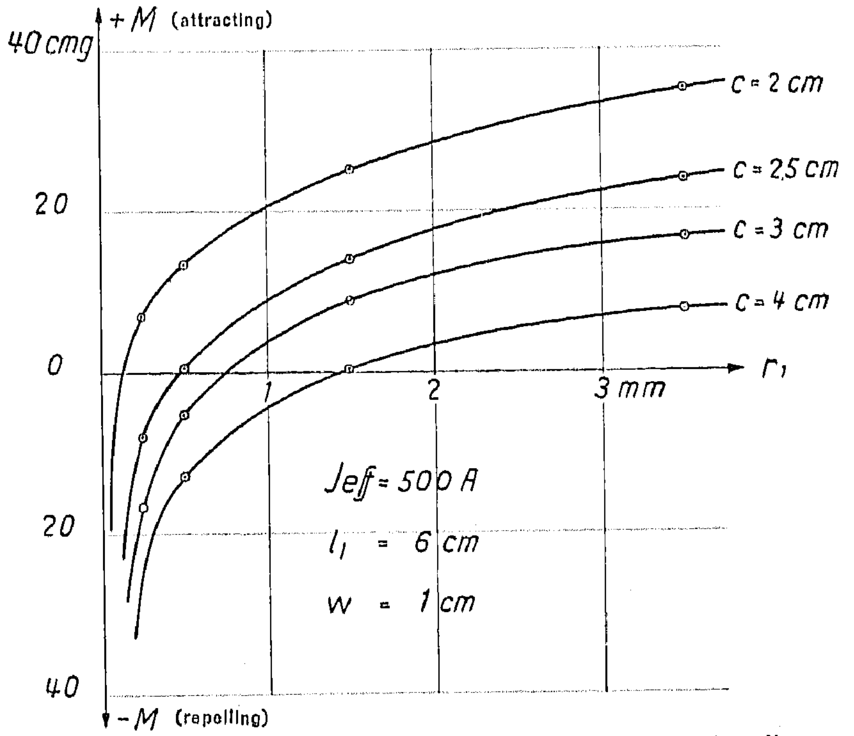


Fig. 11. Torque acting on one finger in function of the contact radius r_1, for different distances c. Arrangement A. $I_{(\mathrm{rms\ value})}$ = 500 amps.

The letters A_1, A_2, A_3, B_1, B_2, B_3, are the abbreviations set out on page 568. The results obtained are likewise plotted in Fig. 9. The curves in Fig. 11 give the torque in function of the contact radius r_1, for a length of contact finger $l_1 = 6$ cm and a variable distance c. The total torque exerted on a finger is further increased by a component which has a repelling effect, due to the current in the interior of conductor. The effect of this component is, however, small. The calculations in the case of the sections m, e, i, d, of the incoming and outgoing conductors represented in Fig. 7 can be carried out without difficulty.

The formulae 8, 9 and 10 and the curves in Fig. 9, show the mode of variation of the torque when passing

from one pair of fingers to a single finger. If we introduce in these formulae, for the distance between fingers, the value infinity, we obtain the lifting force and the corresponding torque for a single finger. The formulae 8 and 10 then give the following expressions for K:—

$$K = \frac{i^2 \times 2}{9.81 \times 10^7} \left[\frac{(l_1 - 2r_1)}{w} + \frac{\sqrt{w^2 + r_1^2} - \sqrt{w^2 + (l_1 - r_1)^2}}{w} + \ln \frac{r_1 \left(w + \sqrt{w^2 + (l_1 - r_1)^2}\right)}{(l_1 - r_1)\left(w + \sqrt{w^2 + r_1^2}\right)} \right] \tag{11}$$

$$K = \frac{i^2 \times 2}{9.81 \times 10^7} \left[\ln \frac{r_1 \left(w + \sqrt{w^2 + (l_1 - r_1)^2}\right)}{(l_1 - r_1)\left(w + \sqrt{w^2 + r_1^2}\right)} \right] \tag{12}$$

The formula 12 agrees with the formulae 4 and 5, which should be the case, as they refer to similar shapes of current conductors. The accuracy of the formula 11 is confirmed by checking it on the basis of the arrangement for leading the current.

III. Conclusions.

We can summarise, in a general way, the results obtained from calculations and confirmed by measurements.

1) It is possible to design an adynamic pair of fingers, i. e. a pair of fingers where the electro-dynamic attracting and repelling forces compensate each other. In fact, an additional attracting torque can be obtained, by adopting a correct design.

2) The value of the attracting and repelling torque, contrary to views held in other quarters, is also dependent to a considerable extent upon the arrangement of the incoming and outgoing conductors, as well as upon the diameter of contacts [2]). The mode of leading the current should be as far as possible in accordance with the arrangement A in Fig. 7.

3) The adynamic pair of fingers is not only determined by the quantity $(l_1/c) = 2.6$, but also by the formula arrived at in section 3 [2]). The value of the repelling and attracting torques can be obtained from it.

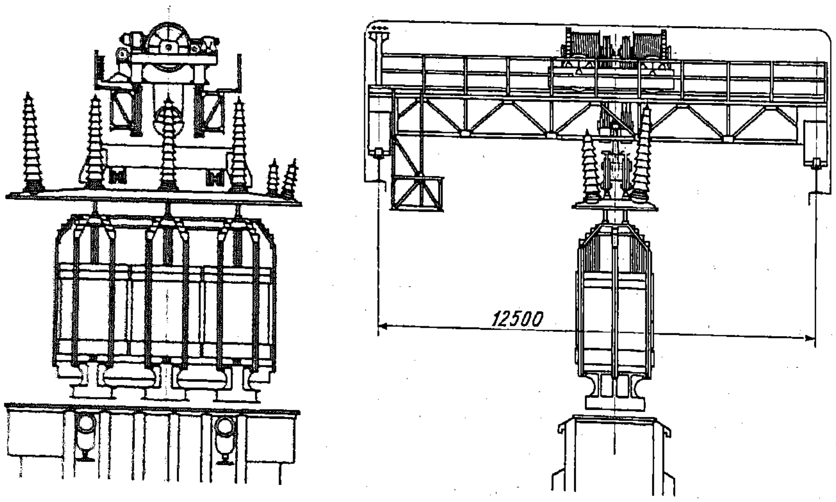
4) Tests with heavy currents, with finger contacts have given good results. It was possible with a single pair of finger contacts, which had not even been designed in a favourable way to switch on a current with a peak value of 35,000 amps. several times, without lifting effect. In fact, this value did not even drop appreciably in the case of contacts with traces of burning due to normal service.

It is a well-known fact that the arrangement with finger contacts is one well suited for switching in parallel several contacts. These contacts present the great advantage that the current is led from several points of contact. It may, in fact, be gathered from tests that there is a certain value above which a current cannot be switched on at a single point of contact, i. e. with block contacts, without lifting effect and resultant "sticking" or welding of contacts.

[2]) Revue Générale de l'Electricité, 1928, pages 217 and 255.

Notes and News Items.

110-ton Travelling Crane. The Oerlikon Company have received an order for a travelling crane of rather special design, for the Ryburg-Schwœrstadt Power Supply Co. The crane is for dealing with a load of 110 tons, and has a span of 41 ft; the lift is 39 ft. The crane is to be used in connection with the erection and dismantling of transformers.



As can be seen from the accompanying illustration, the iron structure is so shaped, in relation to the position of the large insulators fitted to the cover of the transformers, that a considerable saving in height of building has been possible. The speeds are as follows:—

Travelling speed:	23 ft. 7 ins. per min.
Hoisting speed with a load of 110 tons:	1 ft. per min.
Hoisting speed with a load of 10 tons:	9 ft. 2 ins. per min.
Traversing speed:	18 ft. per min.

Luffing Jib Cranes. Jib cranes have always been a favourite type of crane in installations where handling plant is required. It is possible, by using these cranes, to serve a working area, in practically every recess, with plant having relatively small external dimensions and only entailing a moderate expenditure. The other types of handling plant, which can serve a working area equally well, are travelling and gantry cranes; these cranes necessitate, however, a much larger capital outlay, if we include the runway. Travelling and gantry cranes present, however, this advantage over jib cranes, that they require less power for doing the same work. This is due to the fact that the jib crane has to give to the load a circular motion, in order to move it from one point to another in the horizontal plane, while the two other types of cranes can shift the load along a straight line. The length of the path followed by the load is, in the case of jib cranes, always a multiple of that for travelling or gantry cranes, the path being $\pi/2$ longer in the former case.

Means have been sought whereby this drawback of jib cranes could be removed. A design of jib crane has been evolved with luffing gear for varying the radius of jib. Another design provides for a horizontal jib equipped with a crab. The latter design, which is represented in Fig. 1, solves the problem entirely satisfactorily, as the load can move horizontally in a straight line over the working area, without this necessitating a lowering or hoisting motion. When, however, hoisting and traversing gear is fitted on the crab, the equilibrium of crane is unfortunately disturbed, as the weight of crab increases the tilting moment of the crane. When the hoisting and traversing gear is fitted on the crane itself, the crab is, it is true, lighter, but the provisions which have to be made for the guiding of rope lead to an increase in ma-

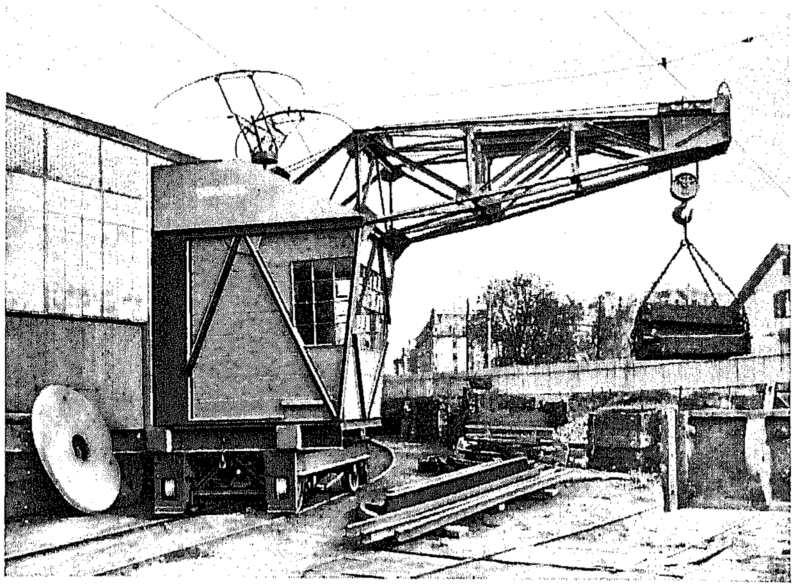


Fig. 1. Travelling jib crane. Lifting capacity 7.5 tons at a radius of 11'5" and 4 tons at a radius of 19'7".

terial required and to a reduction in the efficiency of crane, so that no gain is secured as compared with a jib crane of ordinary design. If the radius of the jib is varied merely by luffing the jib about the jib-foot pivot, the equilibrium of crane is affected in a detrimental way, while there is also the drawback that the load has to be raised or lowered with the jib. In order to remedy the unfavourable conditions created by the displacement of the weight of jib, a design has been evolved with jib coupled by means of levers and rods to the counter-weight or to some part of it, and revolving about a pivoting point, in such a way that the moment of the weight of jib is entirely compensated. Fig. 2 gives a diagrammatical representation of such an arrangement. At the same time, in order to remove the drawback of having to raise and lower the load when luffing the jib, a whole series of designs have been evolved in recent years which solve this problem more or less satisfactorily and where the guiding

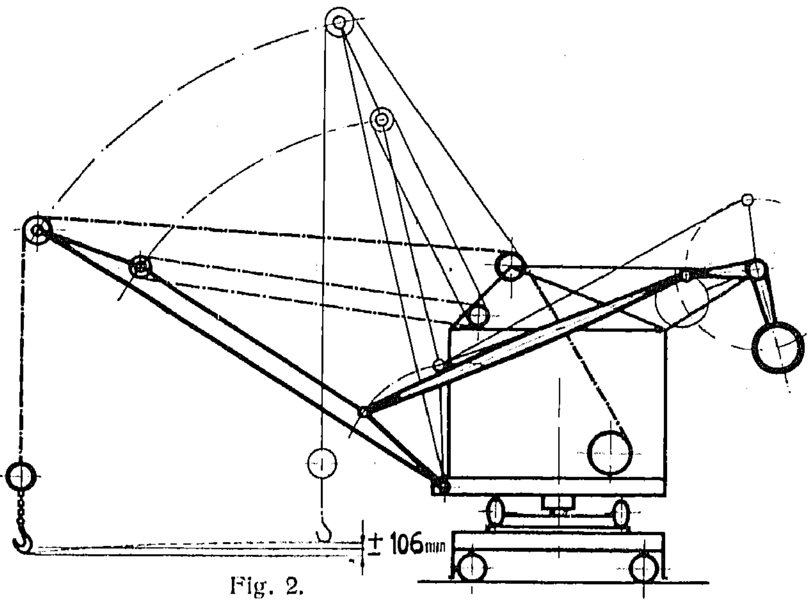


Fig. 2.

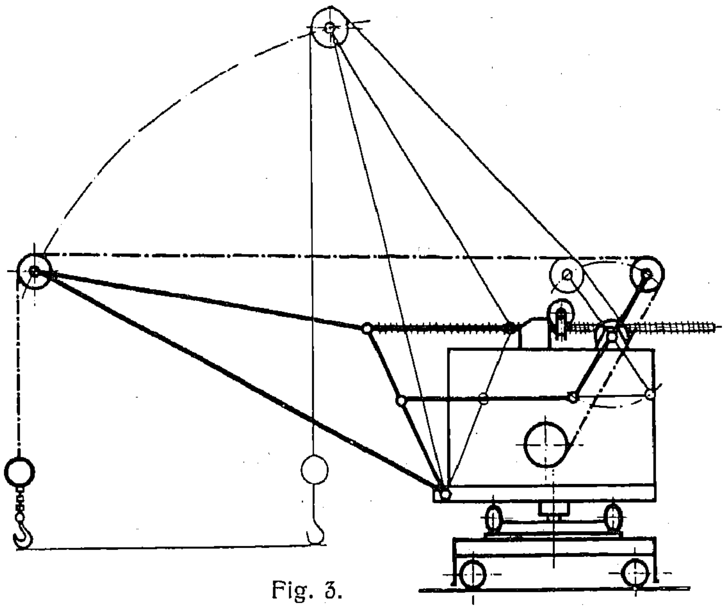


Fig. 3.

arrangement of rope is made dependent upon the motion of jib. The Oerlikon design represented in Fig. 3 is an example of a jib crane of this description. The principle upon which it is based can be seen from the illustration.

The Oerlikon Company have succeeded in evolving a design which, considering its low cost, can be regarded as an economical solution. The method adopted consists in arranging the sheaves serving to guide the rope carrying the load in such a position that when luffing the jib, the load moves in practically a horizontal plane. Figs. 4, 5 and 6 show cranes of this type; Fig. 4 represents a crane with jib raised, while Fig. 5 is a view of the same crane with jib lowered. The moment exerted by the counter-weight on the jib can be gauged from the position of the counterweight in relation to its pivoting point. In Fig. 2, we give a diagrammatical representation of the jib crane shown in Figs. 4 and 5; a curve has been drawn there showing the path described by the load when varying the radius of the jib of a 1.5 ton jib crane from a maximum value of 8 metres (26'3") to a minimum value of 3.5 metres (11'5"). The path is a slightly inclined curve with a difference in level of ± 106 mm (4.18"). The effect of the inclination of this curve, which rises constantly when raising the jib and drops constantly when lowering the jib, on the

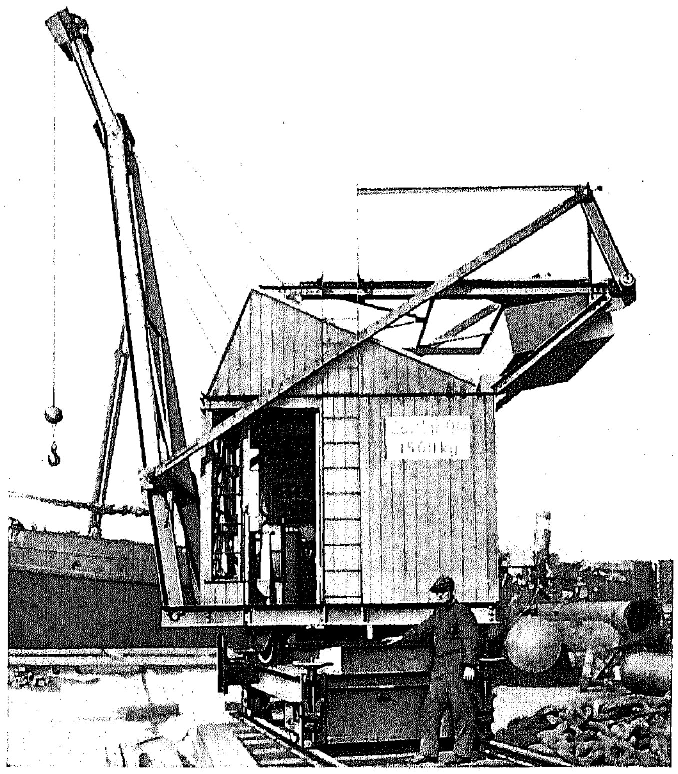


Fig. 4. 1.5 ton travelling jib crane. Minimum radius 11'5". Maximum radius 26'3".

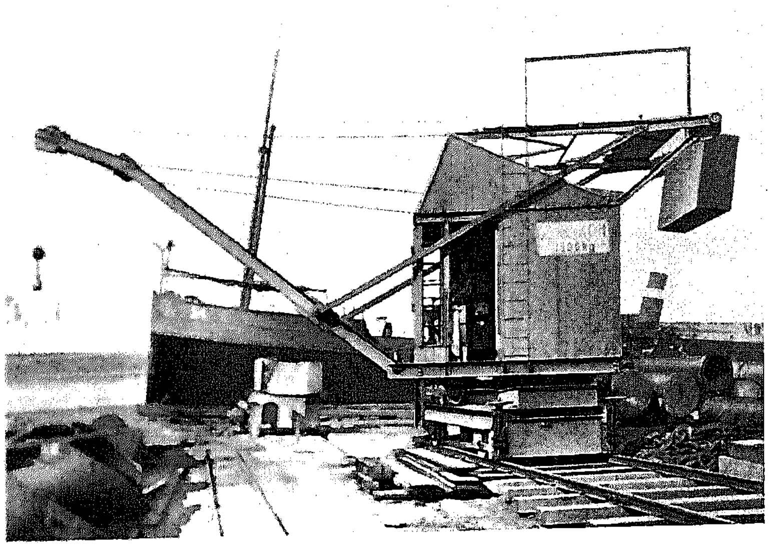


Fig. 5. 1.5 ton travelling jib crane. Minimum radius 11 ' 5 ". Maximum radius 26 ' 5 ".

power required for operating the jib is practically compensated by making the counter-weight follow a path where its moment has a corrective action. The Oerlikon Company have already built a number of cranes of this type which have given very good results in practice.

Fig. 6 represents a jib crane with grab, which is built on the above principle.

Three-phase four-winding Transformers for the Ryburg-Schwœrstadt Power Supply Co. of Rheinfelden, Switzerland. The Ryburg-Schwœrstadt Power Supply Co. is erecting at Schwœrstadt, on the Rhine, a low head power station with a total plant capacity of 140,000 HP. Three important electrical companies, with distribution systems operated at different pressures, are interested in this power station, namely, the Power Supply Company of North-East Switzerland (distribution pressure 145 KV), the Baden Power Supply Company (116 KV) and the Rheinfelden Power Supply Company (45 KV). The power station must be in a position to supply power at will to the distribution system of any of the three companies. This condition has necessitated the use of transformers with three H. T. windings, independent of each other and designed for the whole transformer capacity. The Oerlikon Company have received an order for two such transformers; the first of these is to be put into service in the year 1930. These transformers are three-phase four-winding oil-immersed transformers for outdoor mounting with low-pressure cooling, vacuum oil tank and separate oil coolers. The transformers are each built to the following particulars:—

Rating of each of the four windings 32,500 KVA

Permanent overload capacity for each winding 35,000 KVA

Pressure ratio: 10.5 KV primary to 48/116/145 KV secondary, with two tappings for ± 5 % on the 116 and 145 KV windings.

Frequency: 50 cycles.

Connections: 10.5 KV delta. 48, 116 and 145 KV star, with fully insulated neutral point brought out.

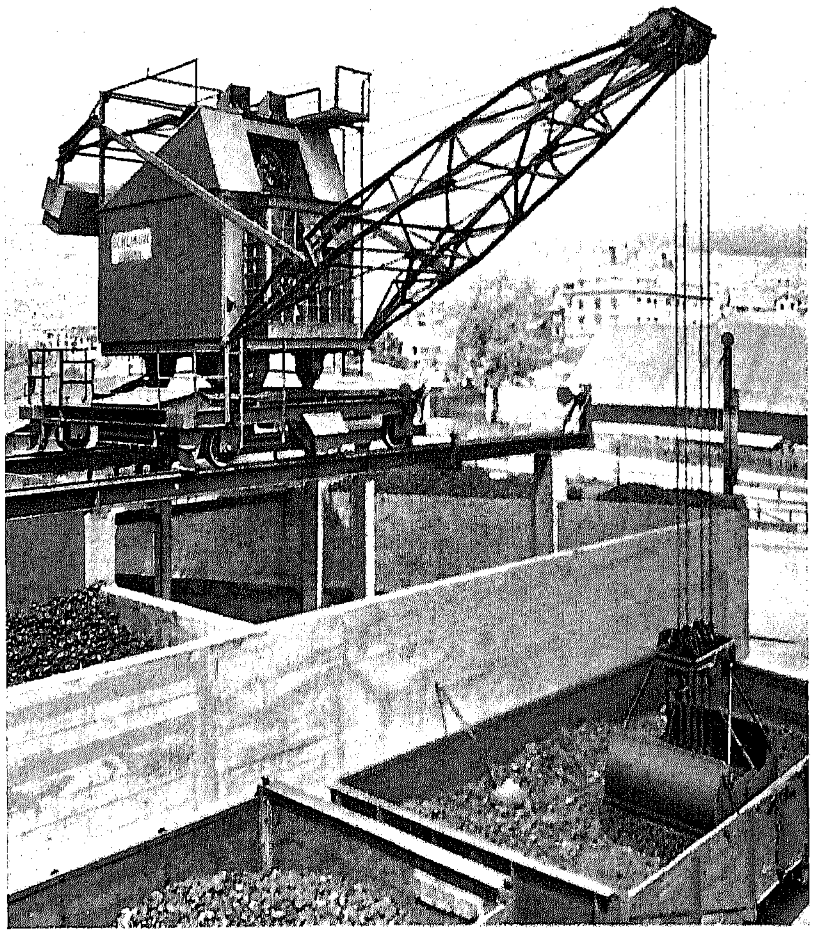


Fig. 6. 2 ton travelling jib crane. Minimum radius 11 ' 5 ". Maximum radius 26 ' 5 ".

The transformation has not only to take place at full capacity, from the L. T. winding at 10.5 KV to one of the three H. T. windings but, also, simultaneously, between the other two H. T. windings, in either direction, for the transfer of power from one of the H. T. distribution systems to the other. The cooler equipments are mounted separately and are dimensioned for dissipating the maximum iron and copper losses, when the transformer is working with any two windings. It will be possible later on to render the cooler equipments capable of dissipating the total losses, when all four windings are carrying 35,000 KVA simultaneously, merely by increasing their size. The short-circuit pressures between the individual windings vary between 8 and 16 %.

The transformers are to be capable of dealing with the short-circuit conditions at the Ryburg-Schwœrstadt power station, where they will be arranged with L. T. winding linked up direct to a three-phase generator of same capacity and with each of the three H. T. windings connected to a very extensive H. T. distribution system.

As regards test pressures, surges and insulation tests between turns, the transformers will comply in these respects, at least with the latest Regulations of the German Association of Electrical Engineers.

The total weight of a transformer, including cooler equipment and oil, amounts to 240 tons. The heaviest part to be transported weighs 80 tons and the heaviest part to be erected, 105 tons.

ATELIERS DE CONSTRUCTION OERLIKON, OERLIKON

BULLETIN OERLIKON

No. 114 — December 1930

Contents: Measures for the mechanical protection of induction regulators against short-circuits.
Tests with a large air cooled oil cooler for transformers.

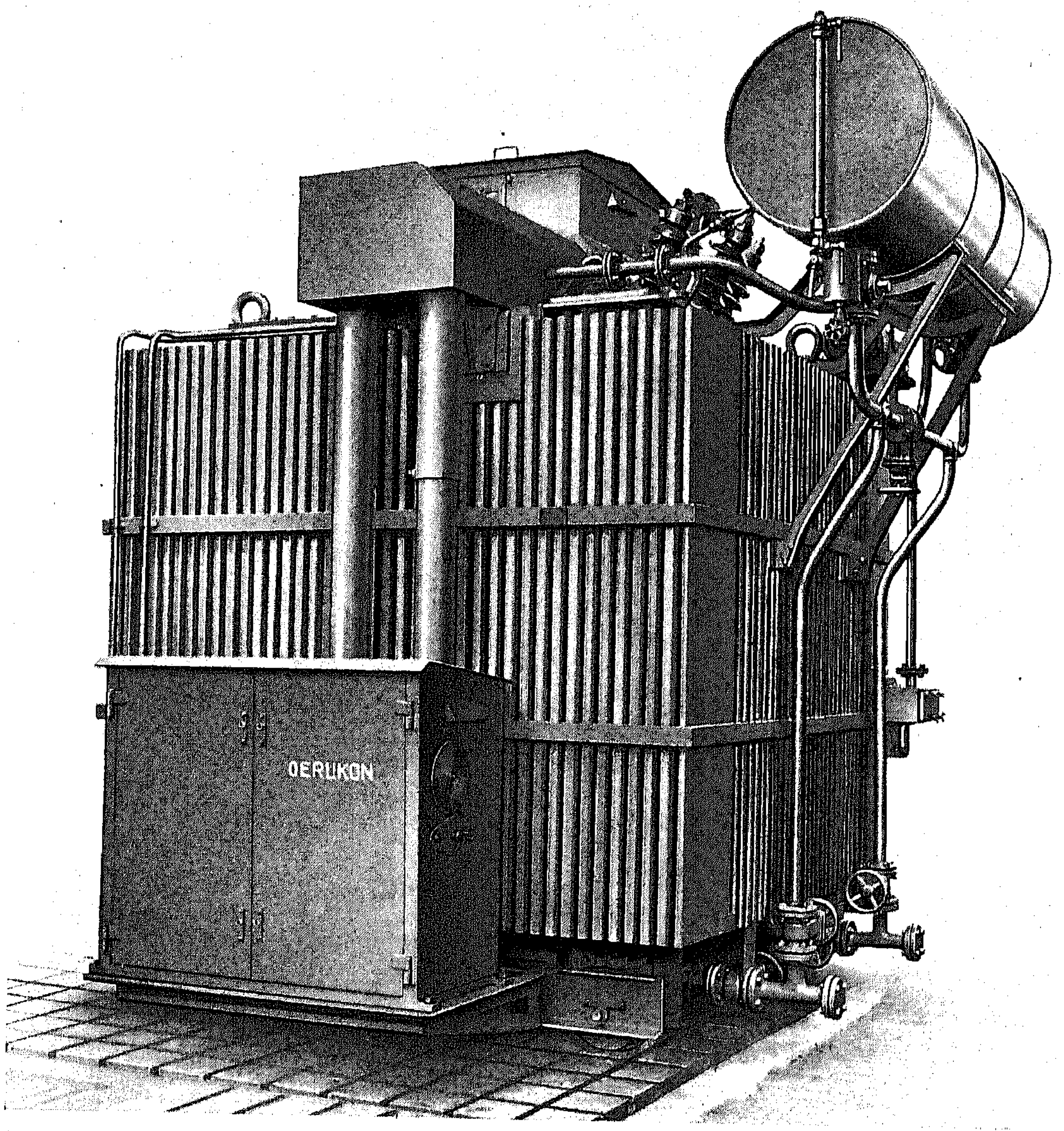


Fig. 1.

Measures for the Mechanical Protection of Induction Regulators against Short-circuits.

The use of induction regulators as pressure regulators in distribution systems, necessitates a design of plant affording every security against short-circuits, as the regulators have to be capable of withstanding the heavy short-circuits liable to occur in such systems. With regard to mechanical strength, the parts of regulator which are mainly endangered, are the windings and the operating gear. We propose to describe hereafter, the measures adopted for the protection of these parts of the regulator.

1) Winding. In order to protect the winding against the heavy dynamic stresses that come into play in the event of a short-circuit, special provision has to be made for the securing of the ends of coils. With simple concentric coil windings, such as used in most cases for regulators, the supporting structure consists of brass bolts and distance pieces of oil impregnated wood or bakelite; these can be clearly seen in Figs. 2 to 4. It is possible, by linking up the bolts by means of straps of flat iron or by a complete iron

ring, to obtain an absolutely stable supporting structure for the winding and to ensure entire mechanical protection for the latter. When designing the winding, special care is taken to ensure that the creeping paths over the wood or bakelite distance pieces have an ample length. Furthermore, in the case of pressures above 6000 volts, mica plates are inserted between the winding and the supporting bolts in order to prevent damage due to corona effect. It is necessary to use, for the supporting bolts, a non-magnetic material, owing to the heavy losses that occur in those parts.

Lattice windings, such as used occasionally for rotors, in the case of low pressure regulators, are held by an inner supporting ring cast on to the press-ring, a wire bandage of non-magnetic material being provided along the outer periphery.

2) Operating Gear. The operating gear of the induction regulator usually consists of a worm wheel, keyed on the rotor shaft, which is driven by means of a worm either by hand or by a servo-motor, through reduction gear. These operating parts can be designed for withstanding a short-circuit torque corresponding to the conditions in the system, which torque can be calculated in advance. In cases, however, where the internal capacity of the regulator is very small as compared with the short-circuit output, the operating gear of the regulator may be subjected to such large forces that the quantity of material required for dealing with them would be quite uneconomical for the size of equipment in question. The Oerlikon Company have, for this reason, designed a slip coupling for use with their induction regulators, affording entire protection against all stresses to which the operating gear of the regulator may be subjected during service.

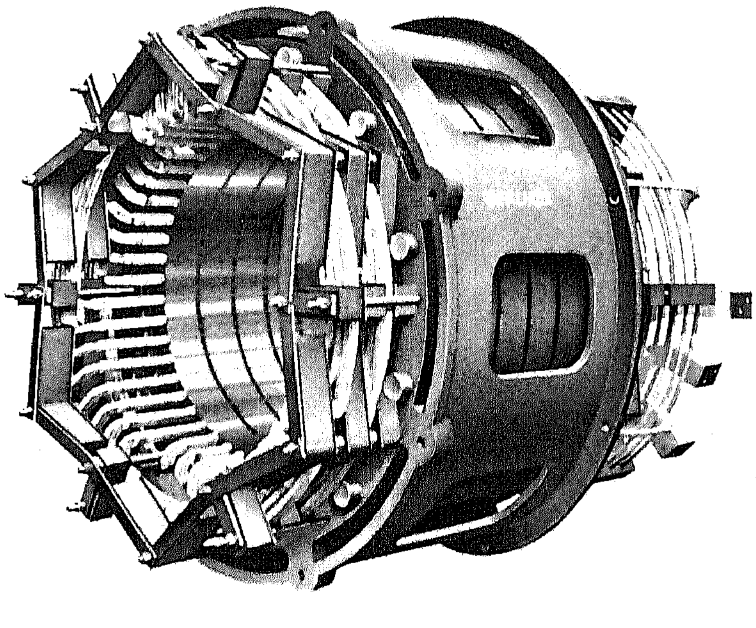


Fig. 2.

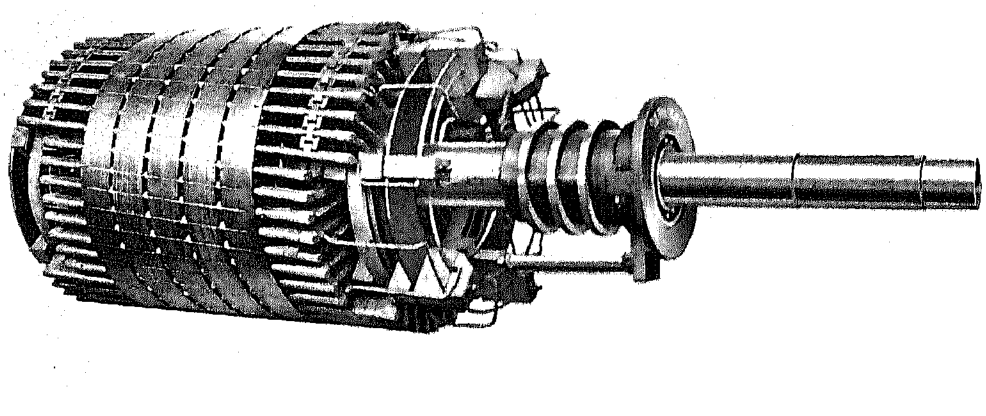


Fig. 3.

The design of the slip coupling is shown in Figs. 5 to 7. A wheel centre is keyed on the shaft of the rotor of the regulator (Fig. 5, right). The worm wheel (Fig. 5, left) is carried by this wheel centre and can revolve on it. Wheel centre and worm wheel are coupled together by means of pins provided on the wheel centre, which engage notches in the worm wheel. The coupling pins are pressed into the notches by means of a spring, the pressure of the latter being adjustable according to the torque.

During service, the slip coupling is adjusted in such a way that the induction regulator and the operating gear remain coupled together up to twice normal torque, that is to say, even in the event of overloads such as may occur in the system. If the induction regulator is subjected to larger torques, as is the case, for instance, in the event of heavy short-circuits, the rotor of the regulator is uncoupled automatically from the worm wheel, as a result of the coupling pins being pressed out of the notches; the rotor then revolves freely about its axis, the angular displacement being governed by the original impulse received. As it may happen that the rotor describes several revolutions, it is necessary to use sliprings for leading the current to the rotor winding. If flexible cables were utilised, as is still often the case on induction regulators of other makes, they would give way, for the reasons described above. The Oerlikon Company have entirely abandoned the latter design, as even under normal working conditions, fatigue phenomena may occur owing to the continual shifting of cables, which may lead to breakages and serious damage.

Induction regulators, when working on load and under normal conditions, present this distinguishing characteristic as compared with induction motors, that the rotor when allowed to revolve freely, does not assume a speed corresponding to the number of poles, but sets itself in a fixed position of equilibrium depending upon the power factor of the system, from which it can only be moved by applying a force corresponding to the load of the regulator at the time. This property is utilised for recoupling the slip coupling, when the regulator is on load, the method adopted being as follows:—

The current holds the rotor securely in its position of equilibrium. The worm wheel is then revolved by hand or by means of the servo-motor, until the pins engage the notches on the worm wheel. The induction regulator, after it has been brought into the position corresponding to the pressure con-

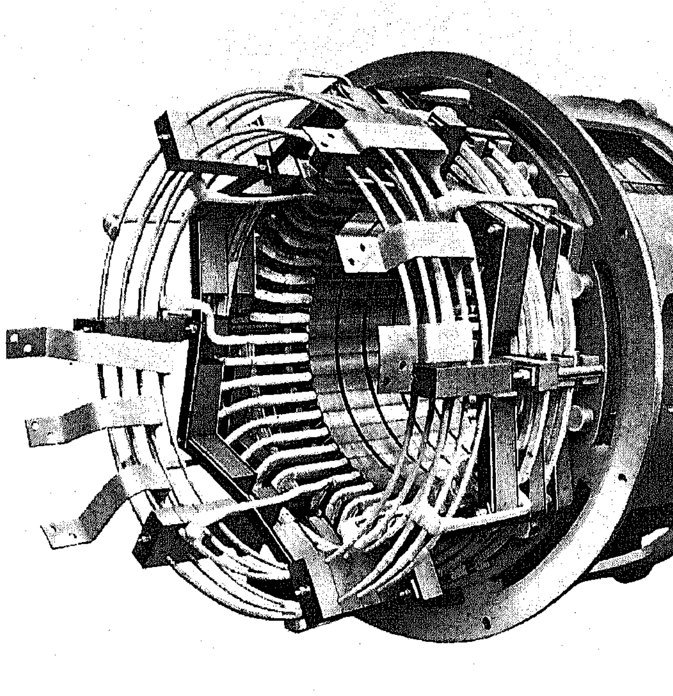
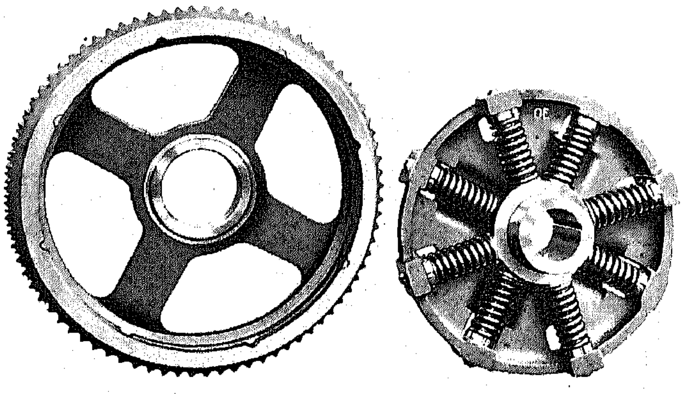
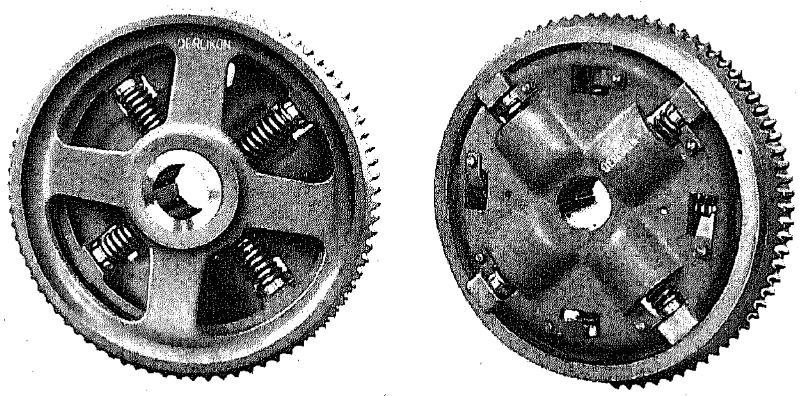


Fig. 4.



Figs. 5a and 5b.



Figs. 6 and 7.

ditions prevailing at the moment is then ready once more for operation. The recoupling under light load conditions takes place in the following way:— The worm wheel remains fast and the rotor is revolved by hand, by means of a lever, until it becomes recoupled.

Although the recoupling of the rotor, by the method described takes place without difficulty, it may be desirable to arrange for entirely automatic recoupling, for instance, in the case of automatic substations or where only inexperienced staff is available. The Oerlikon Company have designed for the purpose, a device for use in conjunction with the slip coupling; the gear in question meets the following conditions:

a) entirely automatic recoupling of the rotor under light-load and full-load conditions,

b) automatic bringing back of the rotor of regulator into the favourable range of operation, where the rotor losses are minimum.

The automatic recoupling and bringing back operation can only be carried out when the regulator is fitted with servo-motor, as the motor itself is used for the bringing back motion. This is, however, no drawback as, in the case of hand operation, the regulator requires, in any case, continual attendance. Before describing the actual automatic recoupling and bringing back operation, we propose to make a few remarks regarding the favourable and unfavourable ranges of operation of the induction regulator.

It is a well-known fact that the induction regulator has, from an electrical point of view, two ranges of operation which are similar with regard to pressure regulation, but dissimilar as regards rotor current. The total rotor current is larger or smaller than the compensation current, according to whether, in the particular range of operation, the magnetising current is added to the rotor compensation current or subtracted from it. This gives, therefore, for the regulator, one favourable and one unfavourable range of operation, as regards rotor losses, referred to the pole pair pitch (in the case of four-pole regulators there are thus alternatively two favourable and two unfavourable ranges of operation). It is a matter of special importance, when paralleling induction regulators, that the latter should work over the same range of operation, so as to prevent circulating currents between the regulators. For this reason, all induction regulators supplied by the Oerlikon Company are marked off for the same (favourable) range of operation.

<u>Automatic recoupling and bringing back device.</u>

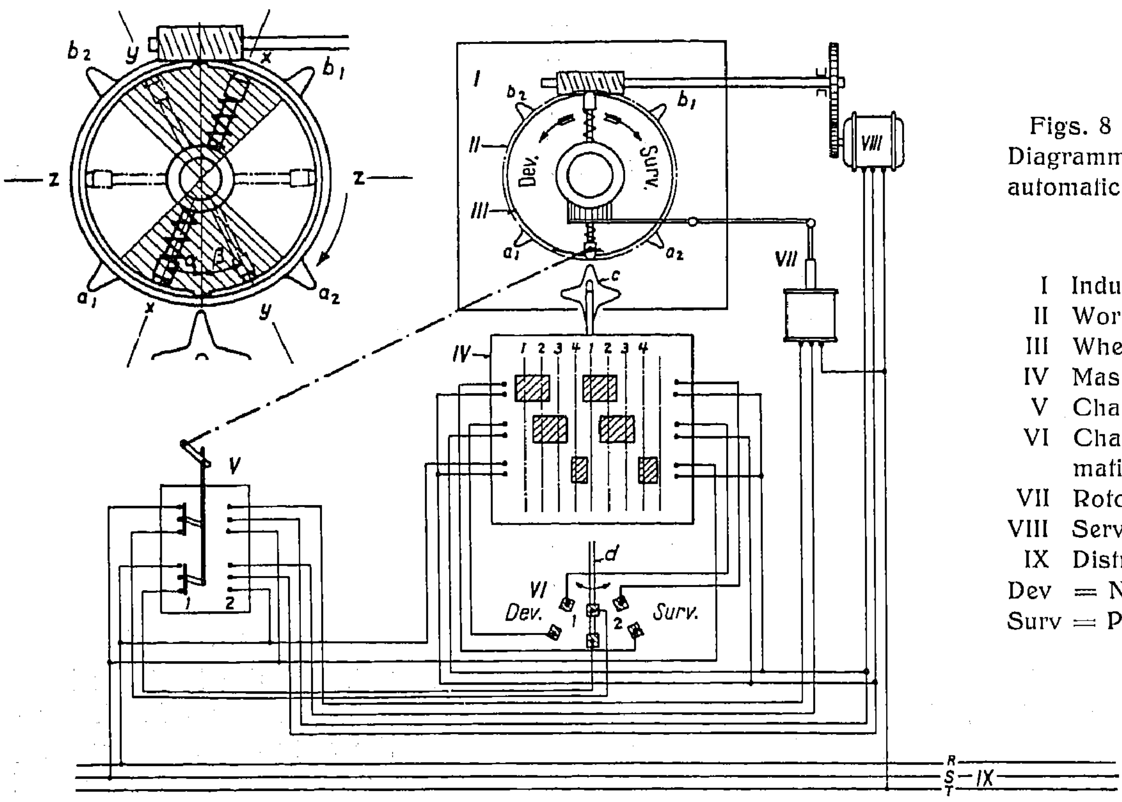
The principle on which this device is based is briefly as follows:— When the slip coupling is uncoupled, as a result of a short-circuit, the backward motion of the coupling pins causes the operation of a change-over switch. This switch cuts out the automatic pressure regulator and, at the same time, connects the servo-motor and braking magnet directly to the system. If the system is live, the rotor of the regulator is held by the braking magnet and the worm wheel is revolved by the servo-motor, until the coupling pins engage the notches. As the pins drop into the notches, the switch comes back into its former normal working position and the regulator is once more ready for service.

We can differentiate three different cases of automatic recoupling, according to the position occupied by the rotor in relation to the worm wheel or to the favourable range of operation, after the uncoupling has taken place. The three different positions are represented in Fig. 8, by the axes x, y and z. The two favourable ranges of operation (four-pole regulators) correspond to the shaded sectors between the noses a_1, a_2 and b_1, b_2, and the two unfavourable ranges of operation to the sector between the noses a_1, b_2, and a_2, b_1. According to the above, the rotor is in the favourable range of operation when in the positions x and y. The difference between these two positions resides in the fact that the coupling pin is, in the former case, at an angle α on the left of the notch in the worm wheel, and, in the latter case, at an angle β on the right. It will be seen from the descrip-

tion of the bringing back operation how far this influences the automatic recoupling. In the case of position z, the rotor has gone over into the unfavourable range of operation.

We are describing below, under 1), the normal pressure regulation process, in order to give a better idea of the working of the individual parts, during normal service. In sections 2a), 2b) and 2c), we deal with the three different cases of recoupling mentioned above, on the basis of Figs. 8 and 9.

1) Normal pressure regulation process. The master switch IV (Fig. 9) is in position 2 and the change-over switch V in position 1. The handle d of the change-over switch VI of the automatic pressure regulator moves into position 2 (positive boost) or into position 1 (negative boost), according to whether the pressure is to be raised or lowered, and connects the servo-motor in circuit, in one direction or the other. The servo-motor revolves the rotor of the regulator, until the correct pressure position is reached. The angular displacement of the rotor for the whole range of operation amounts to 90° (mechanical), in the case of four-pole regulators.



Figs. 8 (on the left, above) and 9. Diagrammatical representation of the automatic recoupling and bringing back device.

I Induction regulator
II Worm wheel of the slip coupling
III Wheel centre of the slip coupling
IV Master switch
V Change-over switch
VI Change-over switch of the automatic pressure regulator
VII Rotor brake
VIII Servo-motor
IX Distribution system
Dev = Negative boost
Surv = Positive boost

In order that there should be no over-regulation beyond this angle, noses a_1, a_2, b_1 and b_2 are fitted to the worm wheel which, when either end position is reached, act on the cam c and bring the master switch from position 2 to position 1 or 3, thus causing the switching off of the servo-motor, in case the latter should tend to drive the rotor beyond the corresponding end position.

2a) Rotor in position x. The backward motion of the pin in the wheel centre of the slip coupling, when uncoupling takes place, causes the displacement of the change-over switch V from position 1 to position 2, owing to the interlocking device. In this position of the change-over switch V, the servo-motor VIII and the braking magnet of the rotor brake VII are connected directly to the system, the change-over-switch VI of the automatic pressure regulator being cut out (see Fig. 9). The rotor brake holds the rotor firmly in position. The servo-motor revolves the worm wheel in the direction of the arrow (see Fig. 8), through an angle α, until the pins engage the notches. When the pins drop into the notches, the change-over switch V is brought into position 1 and the equipment is ready once more for normal service, after the regulator has been brought into the correct pressure position.

2b) Rotor in position y. This position of the rotor differs from that described under 2a) in that the coupling pins are on the right of the notches in the worm wheel. In the case of automatic coupling, the servo-motor is always connected to the system for the same direction of rotation, in order to avoid too great complications. It can easily be seen from Fig. 8 that when the worm wheel is revolved in the direction of the arrow, until the coupling pins engage the notches, the wheel has to describe an angle of $180^0 - \beta$ mechanical (180^0 mechanical corresponds to 360^0 electrical, in the case of four-pole regulators).

In the course of this displacement, the noses a_2 and b_1 shift the master switch from position 2 through positions 3, 4 and 1 back to the normal working position 2. The fact of passing through these different positions is without influence on the bringing back motion, as long as the coupling pins are not engaging the notches and the change-over switch V is thus still kept in position 2. In other respects, the automatic coupling takes place as described under 2a.

2c) Rotor in position z. The change-over switch V is in position 2, as a result of the disengaging of the coupling pins, and the servo-motor and brake magnet are connected to the system. The servo-motor revolves the worm wheel in the direction of the arrow until the two notches are also in the position z and the pins are engaging them. During this displacement of the worm wheel, the nose a_2 shifts the master switch by means of the cam

c from position 2 through the position 3 to position 4. In the position 4 of the master switch, the connections are such that, in spite of the fact that the pins are engaging the notches and the change-over switch is consequently forced from position 2 to position 1, the servo-motor remains connected to the system and revolves the worm wheel, together with the rotor now coupled to it, until the nose b_1 brings the master switch from position 4 to position 1, that is to say, until it has brought back the rotor of the induction regulator from the unfavourable range of operation to the favourable range of operation. In the position 1 of the master switch, the servo-motor is governed again by the operation of the change-over switch VI of the automatic pressure regulator. After bringing the induction regulator to the correct pressure position, the plant is ready once more for operation.

with the existing one is also fitted with automatic recoupling device. In order that, in the event of uncoupling of one or two slip couplings, there should be no disturbance in the parallel operation of plant, the two automatic pressure regulators are interlocked electrically in such a way that the regulation is cut off as long as the two slip couplings are not recoupled.

We still propose to make a few remarks regarding the design of the automatic recoupling device. The two regulators mentioned above are of a special design as regards arrangement of operating gear. The operating gear, including all switches and the braking magnet, for the automatic recoupling device, are fitted in a casing resting on the under-carriage (see Figs. 1 and 10). This arrangement presents great advantages as regards accessibility to the control gear

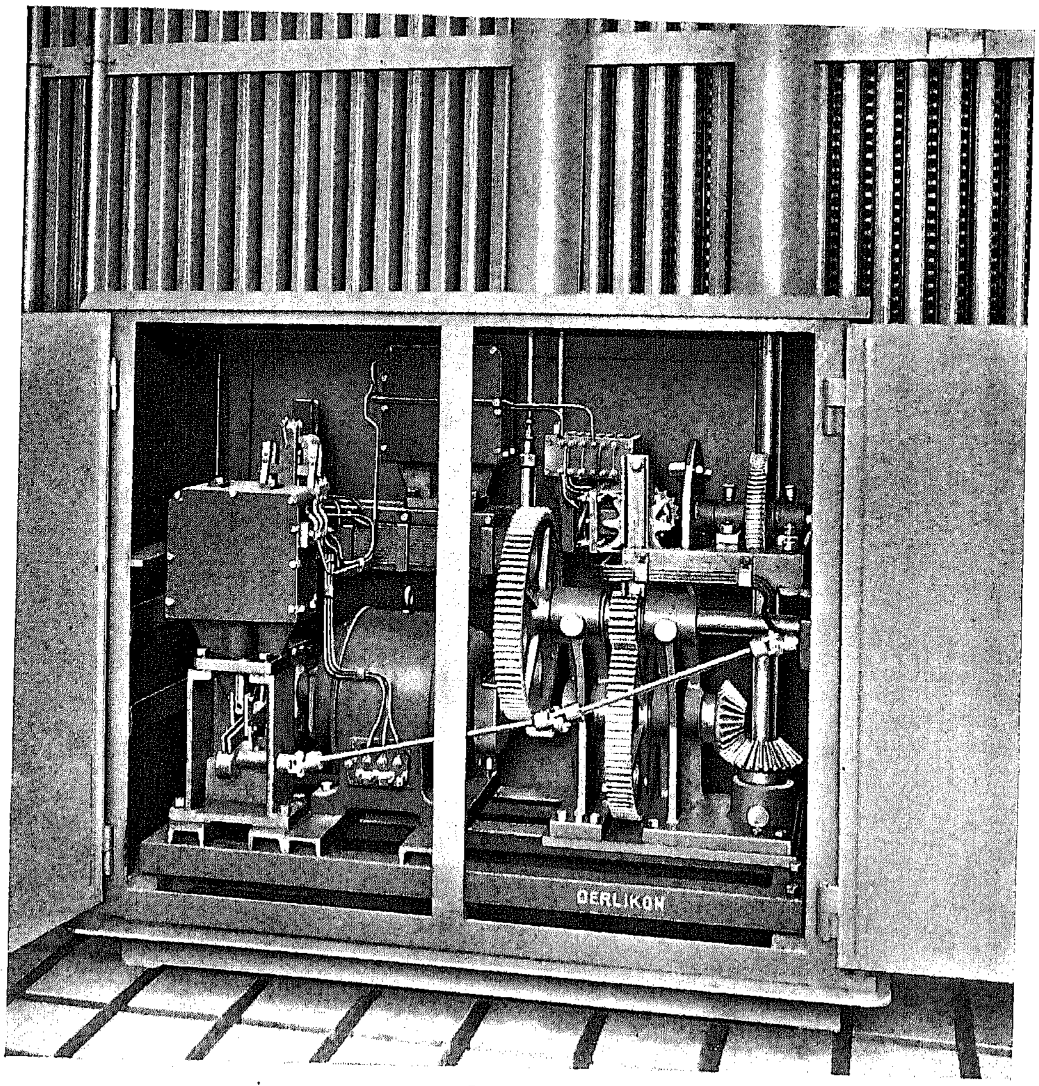


Fig. 10.

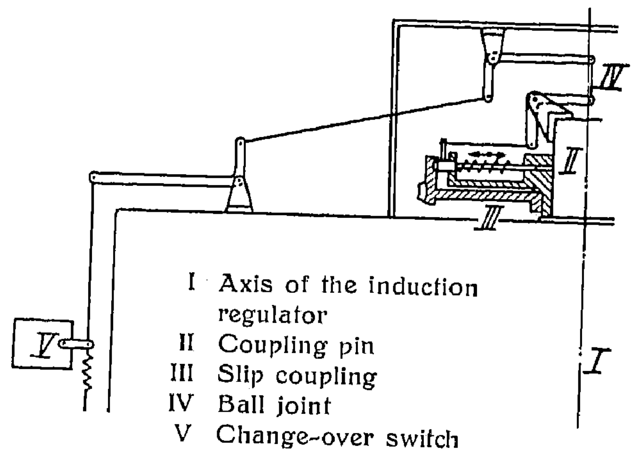


Fig. 11. General arrangement of the gear for interlocking change-over switch and the coupling pin.

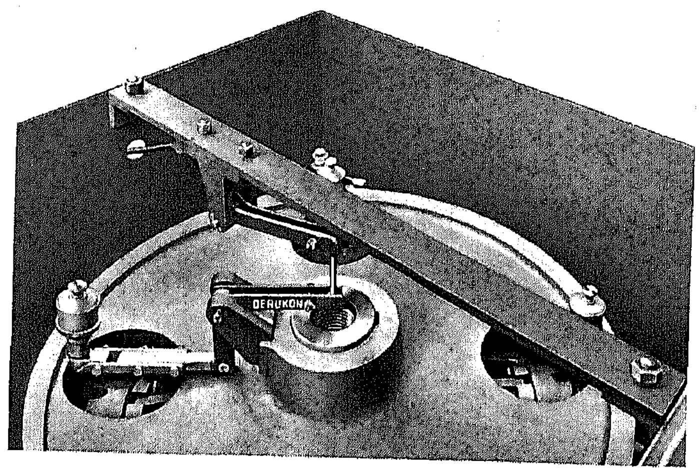


Fig. 12.

Owing to provision having thus been made for the three cases dealt with under 2a), 2b) and 2c) with regard to the automatic recoupling and bringing back of rotor, the latter can be re-coupled and brought back from any possible position.

The device described has been fitted to an induction regulator supplied to the Bernese Supply Co. for their Burgdorf substation where it has been operating for two years without trouble, and during that time a large number of automatic operations have been recorded. The regulator in question is for outdoor mounting and has an external capacity of 6000 KVA at 16,000 volts. Stator and rotor are connected directly to the system. A second regulator was supplied a short time ago. This regulator which works in parallel

and is specially suited for outdoor installations, where all parts have to be well covered. The change-over switch V is linked up to the coupling pin of the slip coupling by means of levers and rods, as shown in simplified form in Fig. 11. The rotor brake is designed as a band brake. The handle of the brake is also linked up to the brake magnets in the casing of operating gear, by means of rods and levers. The master switch IV is operated by means of a cam which is coupled to the upper large worm wheel through gearing with a fixed ratio of 1:1, in such a way that each position of the large wheel corresponds to a definite position of the cam. The control gear and part of the operating gear can be seen in Figs. 10 and 12.

Tests with a Large Air Cooled Oil Cooler for Transformers.

In the case of large transformers, it is necessary to cool the oil by means of special plant. As a rule, the cooling medium used is water or air. In the present case, we are dealing with an oil cooler of the air blast type. The circulation of oil from the transformer to the cooler and back is itself ensured merely by the natural upward motion of the heated oil. In this particular instance, it was not possible to have the transformer (35,000 KVA) in sufficient time for obtaining the necessary data before designing the cooling plant. An auxiliary installation had thus to be provided, which reproduced the transformer in all its parts. The whole testing arrangement is shown in Fig. 1. On the left, we have the cooling plant with the fans, in the centre, a tower, and on the right of the latter, the oil heating plant. The oil is heated with water at a temperature of 80 to 100° C, in four standard oil coolers; it is driven, by means of an oil pump, through the heating plant and then through the large cooler, where it is cooled again. The oil thus always follows the same closed circuit. The tower in the centre of Fig. 1 serves also as equalising tank for the heated oil. A large valve is fitted in the tower, half way between the inlet and outlet of oil. In the case of natural oil circulation, this valve is fully opened. The tests were carried out as follows:— Hot water at 80 to 100° C was obtained from a standard steam boiler. This hot water was drawn from the boiler by means of a centrifugal pump and driven through the heating plant and back to the boiler. The quantity of oil which amounted to about 11,000 litres (2420 gallons) was heated, in approximately an hour, to about 40° C above surrounding atmosphere. It was only then that the fans of the large cooler were put into operation. The temperature of the circulating oil then dropped slowly. The quantity to be measured was the power that could be dissipated by the cooler in the case of a temperature above surrounding atmosphere $\Delta t = 35°$ C. The quantity Δt represents the maximum oil temperature at the inlet of cooler, less the temperature in the neighbourhood of the cooler.

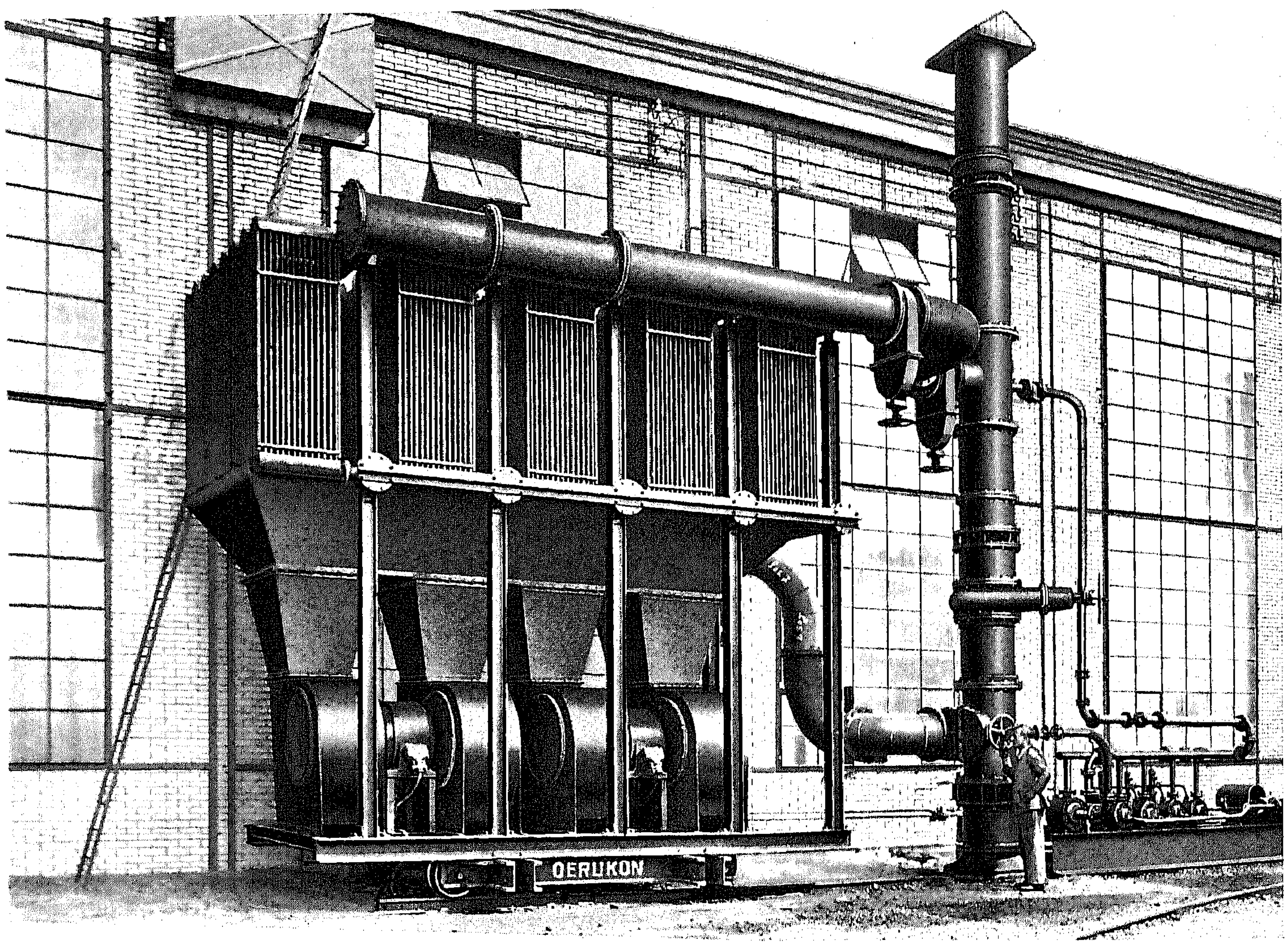


Fig. 1. Arrangement for tests.

The heat dissipated by the cooler can be derived from the quantity of oil in circulation and the difference in temperature between the inlet and outlet of the large cooler, and also from the quantity of heating water and the difference in temperature between the inlet and outlet of heating plant, after deduction of the radiation losses of the heating plant and tower. The radiation losses of the heating plant and

tower were measured separately, the two valves leading to and from the large cooler being closed during this operation. The large valve in the tower was opened. The path followed by the oil was thus through the heating plant into the tower at the top, and out of the tower at the bottom. In this instance, the heating water was not turned on, as the power taken by the closed Oerlikon oil pump was just sufficient to cover the radiation losses for a temperature above surrounding atmosphere $\triangle t = 35^0$ C. Accurate readings were previously taken on the pump, the power consumption for the conditions in question being 13.5 KW.

As the input of pump just covered the radiation losses of the heating plant and tower for a temperature above surrounding atmosphere $\triangle t = 35^0$, this meant that the heat supplied by the heating water was exactly that which would actually be dissipated by the large cooler. In the case of other deliveries and oil temperatures, it was, of course, necessary to make small corrections to the readings.

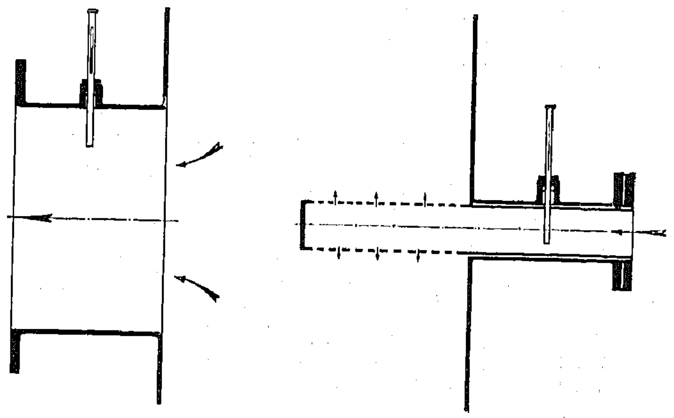


Fig. 2. Strainer at the outlet of oil from the tower.

It may be mentioned that, in the case of all tests, the temperature of the heating water was practically constant, as there was a large quantity of water in the steam boiler.

In the case of operation with natural oil circulation, the large valve fitted in the tower was fully opened. Even before opening this valve, the oil quantity could be correctly adjusted. In fact, it was found, during the tests, that the large valve was not absolutely tight, so that small quantities of oil could leak through it. This oil was, however, in itself sufficient to produce the correct temperature drop in the tower. Provision was made, in the tower, for 5 thermometers evenly distributed along the whole length, between oil inlet and outlet. The correct quantity of oil was obtained when the middle thermometer on the tower gave exactly the mean temperature between oil inlet and oil outlet. After opening the valve, there was, therefore, no alteration in the temperatures in the column of oil in the tower. When the quantity of circulating oil, which only passed across the tower at the top and back at the bottom, was slightly altered, the temperature of the column of oil varied in quite a short time. It was thus possible to obtain easily any desired temperature in the oil column. In the case of natural oil cooling in the large cooler, the oil column in the tower thus remained still, as the oil flowing through the large cooler was delivered right at the top by the oil pump and drawn away at the bottom. In order that the velocity of the oil, when crossing the tower, should not disturb the natural upward motion due to the heated oil, strainers were provided at the oil inlet to and outlet from the tower. As can be seen from Fig. 2, these strainers consist of pieces of tubes which are closed off at the end by means of welded-on end pieces and are provided on the side with a large number of small holes. The velocity of oil, when entering the tower, was in this way entirely destroyed and had to be set up afresh by the column of oil in the tower, in order to cause the circulation of oil through the large cooler.

The following calculations give indications as to the value of the pressure head in the oil column of the tower and the large cooler. When the cooler dissipates 200 KW, and the quantity of circulating oil V amounts to 800 litres per min. (175 gallons per min.), the difference in temperature Δt between the oil inlet and outlet of the large cooler is

$$\Delta t = \frac{200 \times 860}{800 \times 60 \times 0.88 \times 0.48} = 8.5^0\,C$$

It has been found by tests that 1 cm^3 of fluid transformer oil, such as used, expands to the extent of 0.00067 cm^3 per 1^0 C increase in temperature. The oil column l in the tower, referred to the length of 4.1 m. between oil inlet and outlet, thus increases to the extent of $\Delta l = l \times 0.00067 \times \frac{\Delta t}{2} = 4100 \times 0.00067 \times \frac{8.5}{2} = 11.7$ mm. The increase in length of the oil column in the large cooler, which is 2 metres long, is therefore: $\Delta l' = l' \times 0.00067 \times \frac{\Delta t}{2} = 2000 \times 0.00067 \times \frac{8.5}{2} = 5.7$ mm. This gives us the actual pressure head remaining: $h_{eff} = \Delta l - \Delta l' = 11.7 - 5.7 = 6.0$ mm. This pressure head would be capable of creating the following theoretical velocity: $W_{theo} = \sqrt{2g \times h} = \sqrt{2g \times 0.006} = 0.342$ m. The large cooler has a branch with a diameter of bore of 450 mm., so that the theoretical quantity of oil delivered is $V_{theo} = f \times W \times 60 = 15.8 \times 3.42 \times 60 = 3240$ litres per min. The tests have, however, shown that only 800 litres circulate per minute. The greater part of the pressure head is thus lost, owing to the resistances in the piping and in the cooler itself. In the pipeline, there are 5 bends with a radius equal approximately to the diameter of bore of the pipes. Consequently, we have a pressure drop $h_1 = 5 \times 0.25 \times \frac{W^2}{2g} \times \gamma$. Furthermore, there are four sharp bends, which cause a pressure drop $h_2 = 4 \times 1.1 \times \frac{W^2}{2g} \times \gamma$. The total resistance is thus $h_{tot} = h_1 + h_2 = 5.65 \times \frac{W^2}{2g} \times \gamma$. This means that there only remains, for creating the velocity, a pressure head $h_w = h_{eff} - h_{tot} = 0.006 - (5.65)\frac{W^2}{2g} \times \gamma$. The reading obtained for the actual velocity W_{eff} was $W_{eff} = \frac{V_{eff}}{f \times 60} = \frac{800}{15.8 \times 60} = 0.845$ dm.

Hence: $\frac{W^2}{2g} \times \gamma = \frac{0.0845^2}{2g} \times 0.88 = 0.00032$ m. This gives us $h_w = 0.00600 - 5.65 \times 0.00032 = 0.00600 - 0.00180 = 0.00420$ m. This head would still create a velocity $W' = \sqrt{2g \times 0.00420} = 0.286$ m. The figure obtained was, however, only $W_{eff} = 0.0845$ m. We thus see that the inner flow causes a large loss in pressure head. We have $W'\alpha = W_{eff}$; $\alpha = \frac{W_{eff}}{W'} = \frac{0.0845}{0.286} = 0.295$.

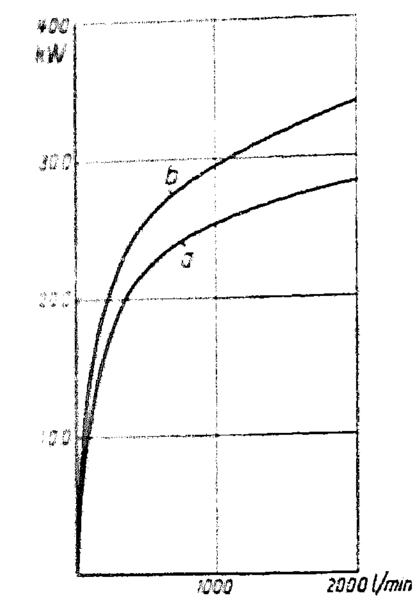


Fig. 3. Power dissipated in the case of different quantities of oil and Δt = 35° C, when using two fan sets, without screens (a), with screens (b).

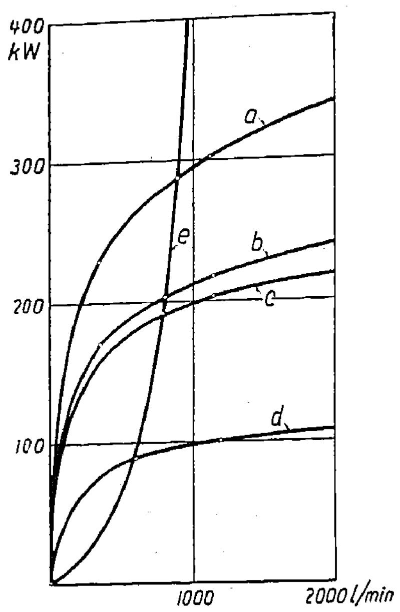


Fig. 5. Power dissipated in the case of different quantities of oil and Δt = 35° C, when using two fan sets (a), when using one fan set (b and c), when working without fan (d), and with natural oil circulation (e).

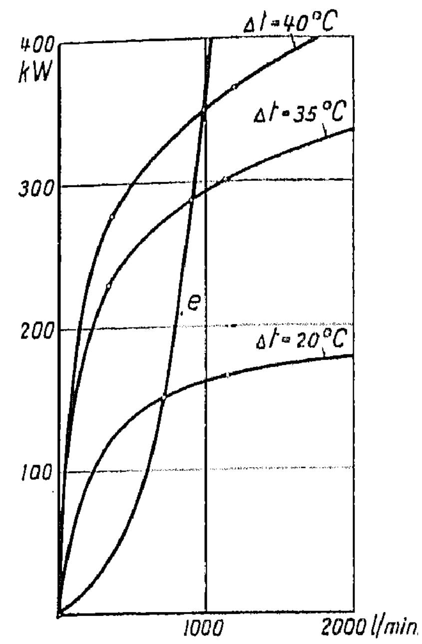


Fig. 6. Power dissipated in the case of different quantities of oil and Δt = 20, 35 and 40° C, when using two fan sets.

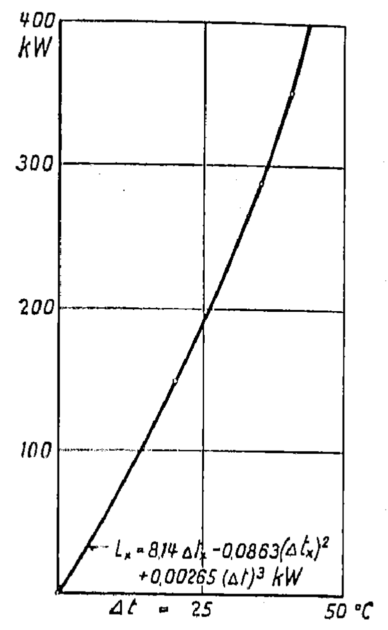


Fig. 7. Curve giving the power dissipated in function of Δt, in the case of natural oil circulation, when using two fan sets.

First series of tests. It was desired to find out the influence of an arrangement with screens for diverting the air. The results of tests are plotted in the form of curves in Fig. 3. Curve (a) represents the power dissipated in KW, in the case of different quantities of circulating oil, when no screens are used. Curve (b) shows the results obtained when screens are provided. It will be seen that a considerably larger amount of power is dissipated, when use is made of screens, although the power consumption of the fans is only 12 KW (without screens 14.4 KW). Fig. 4 shows the manner in which the air is guided. The screens are arranged in such a way as to cause the air to flow in a transversal direction to the cooling tubes.

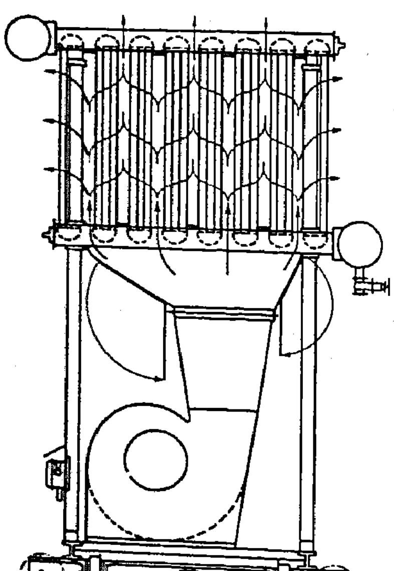


Fig. 4. Arrangement for guiding the air.

Second series of tests. Tests were carried out with two fan sets and without fan. We give the results for all these tests in Fig. 5. Curve (a) corresponds to the test with two fan sets. The figure obtained for natural oil circulation was 900 litres per minute. A further test was carried out with one fan set, first with the air distributed over the whole cooler equipment (curve b) and then with the air distributed over half the cooler plant, the other half being only cooled by natural air circulation (curve c). We see that when one fan set works in conjunction with the whole cooler equipment, the power dissipated is larger than when the fan set works only in conjunction with half the cooler plant and the other half works with the natural air circulation. It may, however, be noted that the power consumption of the fan was 6.6 KW in the latter case. Another test was carried out with natural air circulation, that is to say without fans, in the case of the whole cooler (curve d).

In each instance, tests were also made with regard to natural oil circulation. Curve (e) in Fig. 5 gives the limit line obtained. Tests show that beyond the limit line e, it is not possible to gain much by using an oil pump (see curve b), as the conditions corresponding to this limit line are very favourable for natural oil circulation.

Third series of tests. All the preceding tests referred to a temperature above surrounding atmosphere $\Delta t = 35^0$ C. It was, further, desired to ascertain the conditions for other values of Δt. We give, in Fig. 6, the results of these tests. Measurements were made for $\Delta t = 20^0$, 35^0 and 40^0 C.

Unfortunately, the test installation did not permit of higher values. It was, however, possible to obtain the shape of the limit line, e, so that the conditions for higher values of Δt could be determined, with a fair amount of accuracy, by calculation.

In Fig. 7, we have plotted the readings in function of Δt. We obtain, for this curve, the following equation:—

$$L_x = 8.14 \times \Delta t_x - 0.0863 \, \Delta t_x^2 + 0.002565 \, \Delta t_x^3 \text{ KW.}$$

For $\Delta t = 60^0$ C, we would obtain an output L = 700 KW, in the case of the cooler in question.

SUMMARY OF CONTENTS OF

BULLETIN OERLIKON

1931

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No. 115 — January 1931

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On the behaviour of commutators of the driving motors of the Oerlikon single-phase locomotives Series Ce $^{6}/_{8}$ III und Ae $^{4}/_{7}$ supplied to the Swiss Federal Railways.

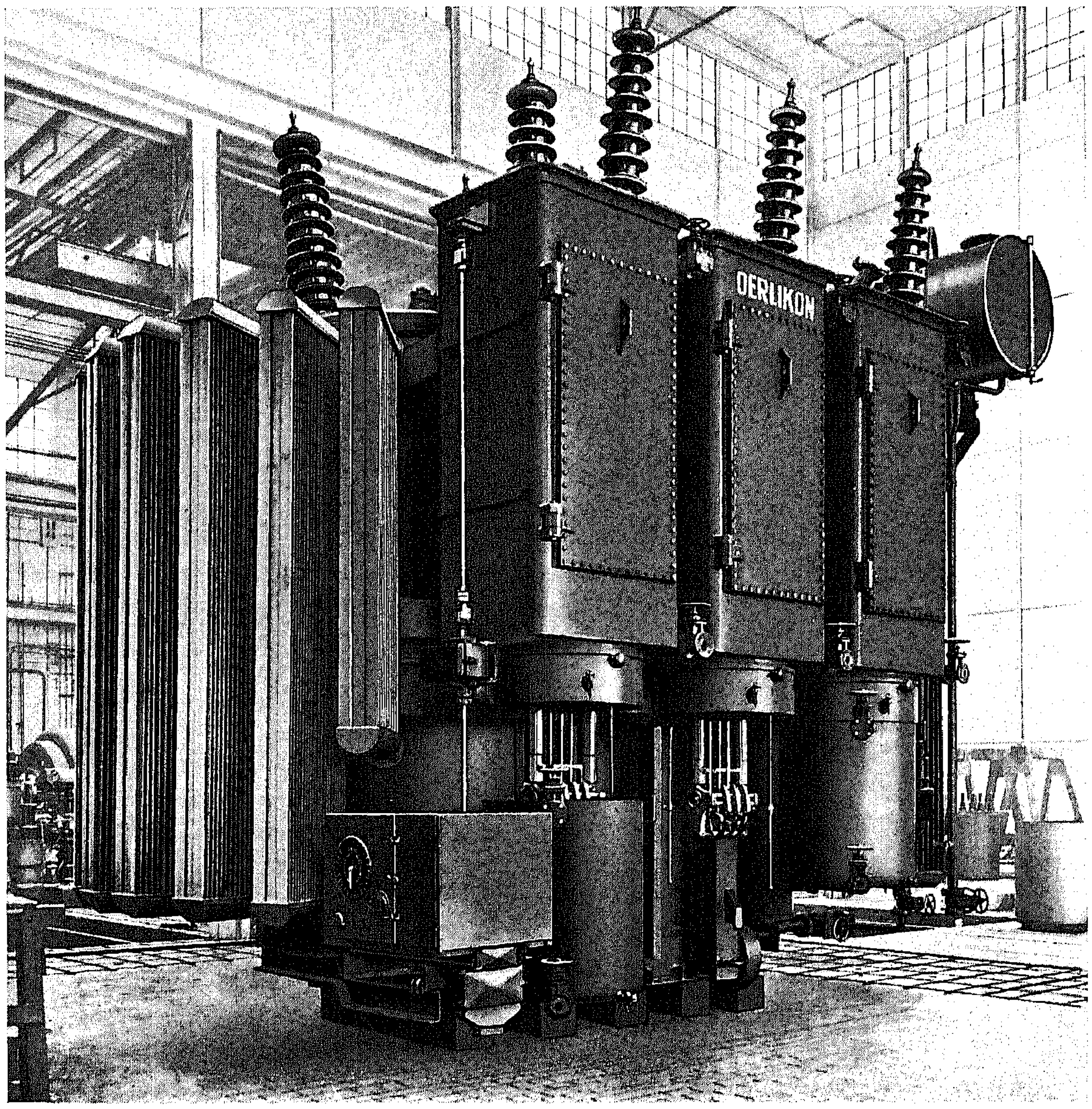


Fig. 1. Three-phase regulating transformer for 10000 KVA, H. T. side 135000 volts ± 3.7%, L. T. side 62575 volts with ± 10 steps each for 1257.5 volts, 50 cycles.

Regulation of Transformers on Load by Means of Step-switches.

The idea of regulating the pressure of a system by altering the number of turns of the transformer feeding this section of the system is undoubtedly as old as the general application of transformers themselves. This question has, however, now gained increased significance owing to the growing practice of interconnecting systems. As far back as twenty years ago and even earlier, the Oerlikon Company built step-switches embodying many of the ideas which are now claimed as new; these step-switches were evolved from the battery switches, such as used for batteries of accumulators, and were provided, as in the case of these, with a bridging resistance, in order to avoid the short-circuiting of two neighbouring tappings, when passing from one step to the other, without interruption of circuit. Furthermore, these step-switches embodied, even then, a circuit breaker, so that the tapping switch or step selector, which was built

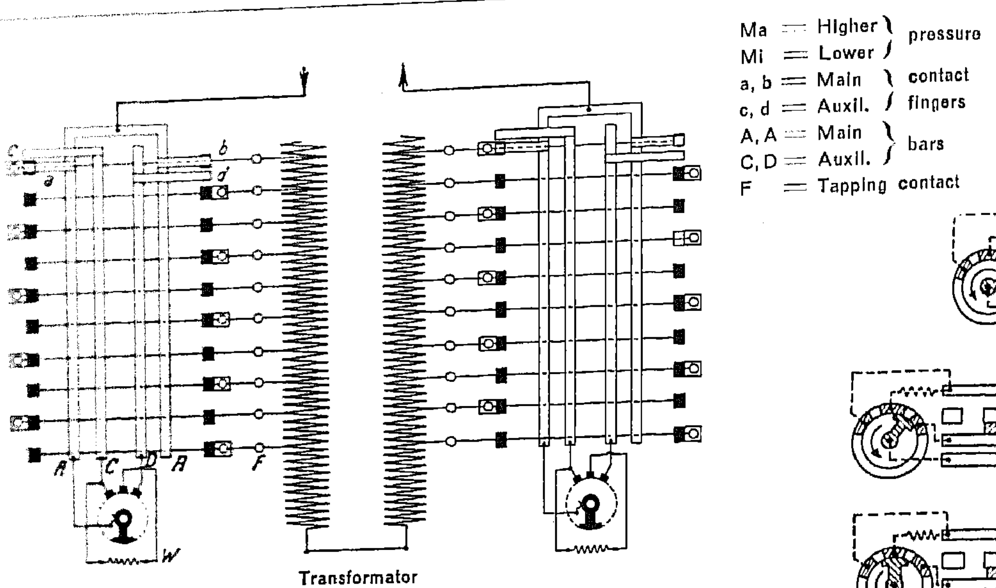


Fig. 2 a. Diagram of connections of an Oerlikon step-switch supplied in 1911.

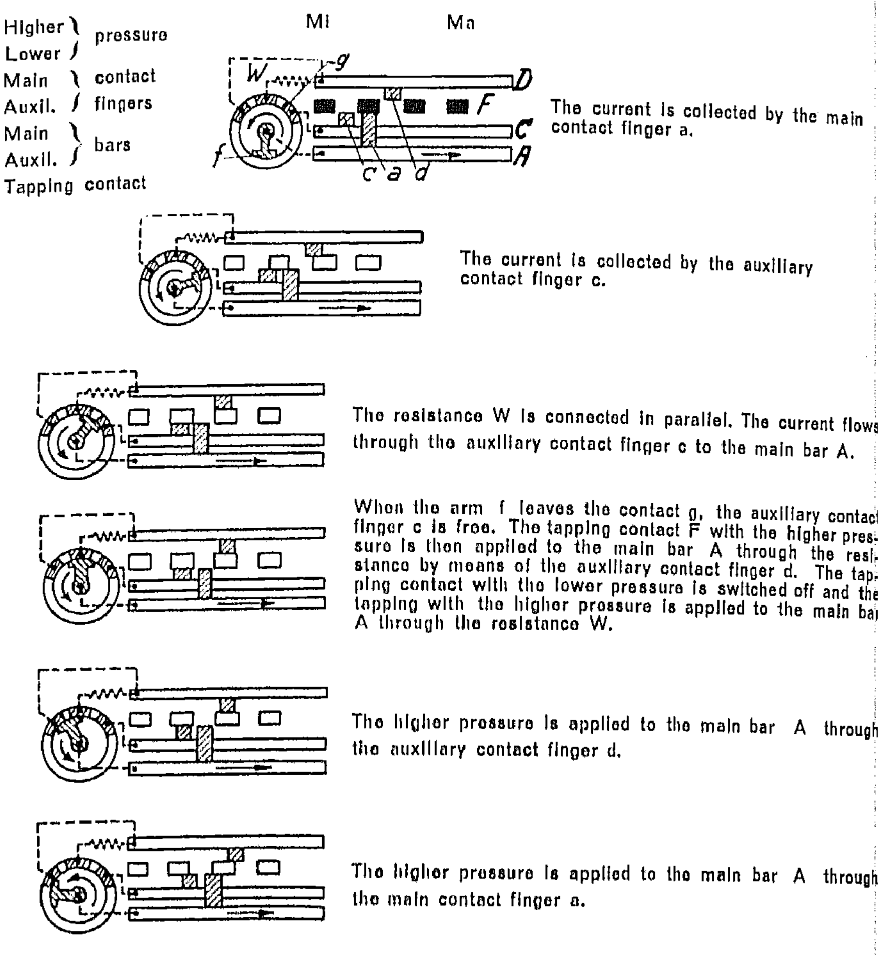


Fig. 2b. Diagrammatical representation of the mode of operation of the step-switch in Fig. 2 a.

as a sliding switch, could be operated with the current cut off. Fig. 2 a shows the mode of connection of such a step-switch, while Fig. 2 b is a diagrammatical representation of its mode of operation.

In the meantime, however, induction regulators had been brought to a high degree of efficiency, by the Oerlikon Company in particular, and had become very reliable and economical regulating appliances which further permitted of the regulation without steps and in a continuous manner, so that it was only occasionally that step-switches were still used.

It may, therefore, be asked why this imperfect means of regulation is now often being reverted to; this must be ascribed to the constant increase in the pressure of systems. In view of this, each of these appliances, the induction regulator and the step-switch, have been allotted a certain field of application. Induction regulators, like generators, to which they are very similar as regards design, can, at the present stage of electrical development, only be insulated economically up to a given maximum pressure. Above that value, induction regulators have to be connected through series and excitation transformers. In the case of step-switches, however, this is not necessary. It will thus be found that for all pressures which can be obtained directly from generators, the induction regulator is the more economical appliance and for all higher pressures, the step-switch. As a result of the progress in the science of insulation, the limits of the two fields of application have been raised. Cases may, of course, also occur where the two fields of application overlap. When it is an essential condition that regulation should be continuous without steps, induction regulators can alone be considered. On the other hand, when the number of pressure steps required is small, the step-switch may be the more advantageous regulating appliance, even in the case of low pressures.

The original method of pressure regulation on load by means of transformers, consisted in switching off the transformers, working in parallel, one after the other, by means of their oil circuit breakers, and in altering the number of turns to the extent required by means of tapping switches for operation with current cut off, after which the transformers were switched on again. Up to the moment where all the transformers had been switched over, they worked with pressure ratios differing from each other. The equalising current which occurred was damped down by the leakage reactance of the transformer, to a value presenting no longer any danger. This method is, of course, unsuitable when the alterations in pressure are frequent. It constitutes, however, the basis of the "split conductor" or "parallel windings" method, often resorted to in America. This method provides for the subdivision of each transformer winding into two parallel branches I and II (Fig. 3 a). Either branch can be switched off by means of the oil circuit breaker O_I or O_{II} and regulated by means of the tapping switch A_I or A_{II}, respectively. This arrangement can only be considered in the case of very large units where it is necessary, owing to the additional losses due to heavy currents, to sub-divide the winding. In the case of the capacities of units and pressures resorted to in Europe, such cases seldom occur. The

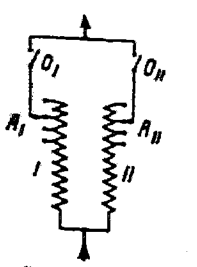


Fig. 3 a. Pressure regulation by means of transformers with winding subdivided into two parallel circuits.

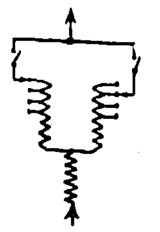


Fig. 3 b. Pressure regulation by means of transformers with winding only partially subdivided into two parallel circuits.

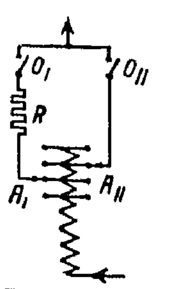


Fig. 4. Fundamental diagram of connections for step regulation with bridging resistance.

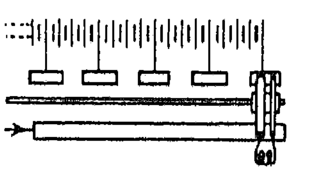


Fig. 5. Fundamental diagram of connections for battery switch.

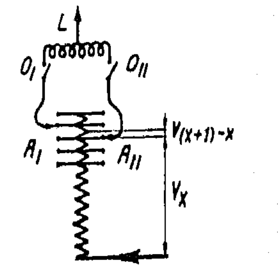


Fig. 6. Fundamental diagram of connections for step regulation with balancer coil.

general subdivision of transformer windings would lead to an excessive increase in the price of transformers.

In order to reduce the price of the transformer, an arrangement has been adopted where the winding is only partially subdivided into two parallel circuits (Fig. 3 b). The natural reactance of the subdivided portions then suffices no longer to keep the equalising current within permissible limits and must be increased artificially. This means a complication of the transformer, which is weakened as regards ability to withstand short-circuit stresses.

and position of this damping impedance in the circuit. If this impedance is inserted, as shown in Fig. 4, in the manner of a choking coil or of a resistance, between a tapping switch and the corresponding oil circuit breaker, we have a diagram of connections which is identical with that for battery switches (Fig. 5). The bridging coil or the bridging resistance then only works on load during the duration of the passage from one tapping of the transformer to the next. It is, therefore, calculated accordingly and has only very small dimensions. In order to obtain a given number of pressure steps, the trans-

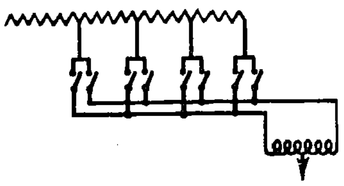


Fig. 7. Step regulation by means of two contactors per transformer tapping.

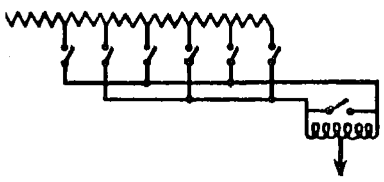


Fig. 8. Step regulation by means of one contactor per transformer tapping and one bridging contactor.

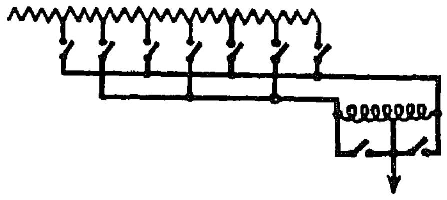


Fig. 9. Step regulation by means of one contactor per transformer tapping and two bridging contactors.

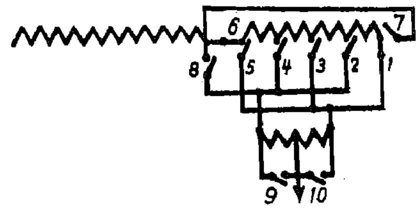


Fig. 10. Step regulation as shown in Fig. 9, but with provision for reversal.

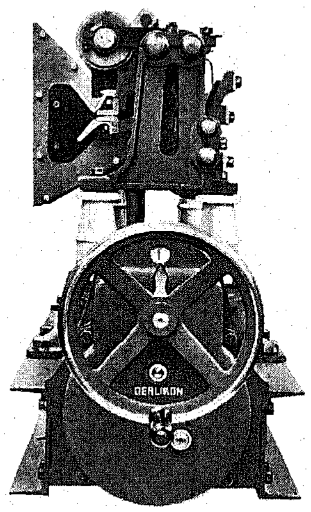


Fig. 11. Side view of the step-switch represented in Fig. 12. Arc chute of the first contactor removed.

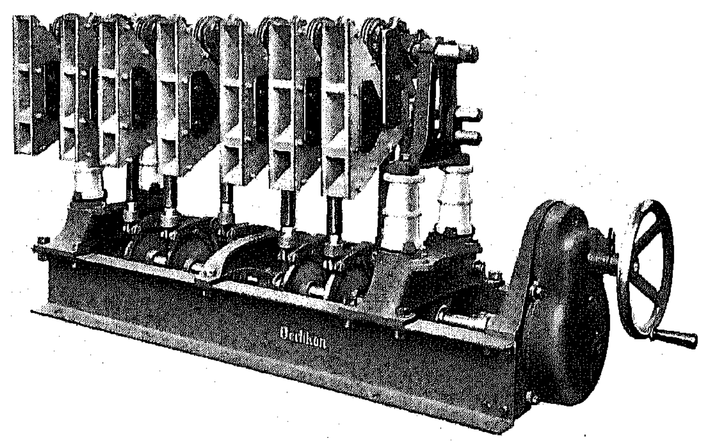


Fig. 12. Single-phase step-switch of the air break type for a transformer for use in conjunction with furnaces, for 4130 KVA, 10000 volts, 50 cycles, with 10 steps each for 7 %, with hand operating gear.

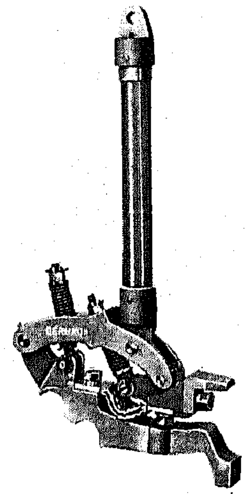


Fig. 13. Contact unit of the step-switch represented in Fig. 19.

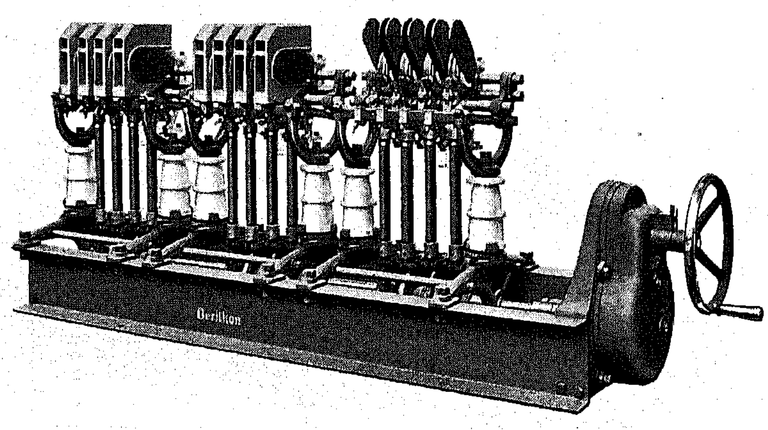


Fig. 14. Three-phase step-switch of the air break type for a transformer for 1500 KVA, 9500 volts, 50 cycles, with 4 steps each for 2.6 %, with hand operating gear.

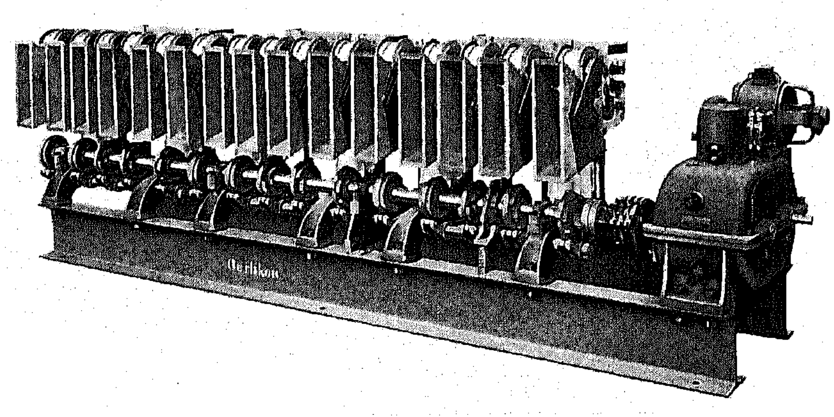


Fig. 15. Three-phase step-switch of the air break type, for a transformer for 7000 KVA, 6700 volts, 50 cycles, with 5 steps each for 2.2 %, with remote control.

The most favourable solution with regard to the transformer is to dispense entirely with parallel circuits. It is, however, necessary in such a case, to insert a special impedance in the circuit of the equalising current, in order to reduce the current. There are two characteristic arrangements for step regulation of transformers, according to the nature

former must be provided with the same number of tappings. If we insert the damping impedance in the manner of a choking coil, as shown in Fig. 6, and arrange it in two halves, between the outgoing line L and either of the two switches O_I and O_{II}, the coil being dimensioned for permanent magnetisation as a balancer, we have as further pres-

sure step, when the tapping switch is on two consecutive contacts, the mean pressure between two tappings. If the step pressure is to correspond to the pressure of one tapping, the two tapping switches will be in the same position. The two halves of the choking coil carry currents with the same value, but opposed in direction, so that there is no magnetisation. The choking coil only gives rise to a negligible ohmic pressure drop. The diagram in Fig. 6 thus differs from the diagram in Fig. 4, in that it is possible to obtain, with the same number of tappings on the transformer, twice as many pressure steps.

With the arrangement shown in Fig. 6, the passage of the two tapping switches A_I and A_{II} from one tapping to the other takes place, as in the case of Fig. 4, with the current cut off, that is to say, only after the circuit in question has been interrupted by the corresponding switch O_I or O_{II}.

desired step pressure is to correspond to the pressure of one tapping, the two contactors on the same tapping are closed and the choking coil is bridged over. If it is desired to have an intermediate pressure between tappings one contactor is closed in the case of either of the two neighbouring tappings in question and the coil works as a balancer. This arrangement necessitates the use of two contactors per transformer tapping, i. e. $(n + 1)$ contactors for n pressure steps (= positions of the step-switch).

The bridging coil can, however, also be short-circuited by means of a single central contactor. It is possible by resorting to this solution, which is represented in Fig. 8, to reduce the number of contactors to $\left(\frac{n-1}{2}+2\right)$ for n pressure steps.

Both in the case of the arrangement shown in Fig. 7 and that represented in Fig. 8, the current which divides

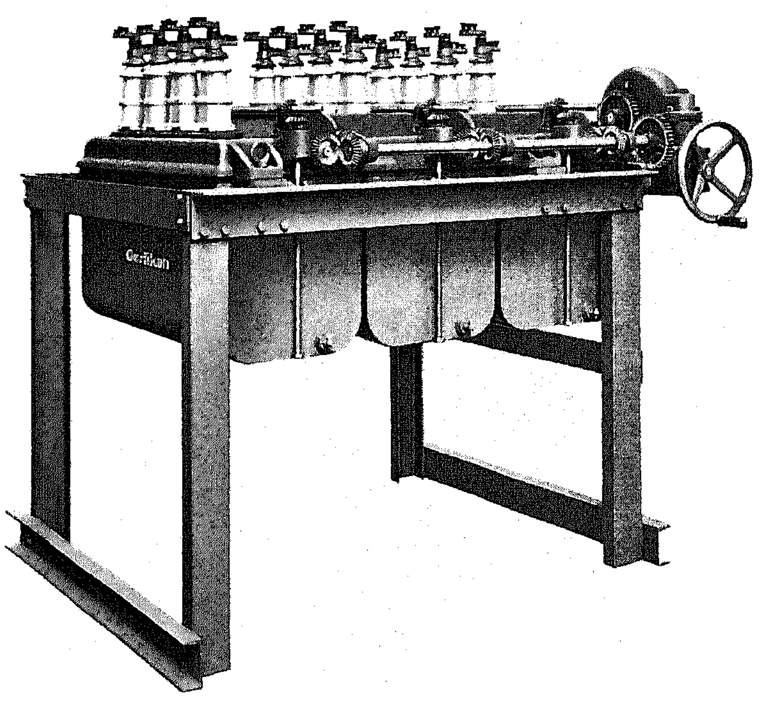


Fig. 16. Three-phase step-switch of the oil-immersed type, for a transformer for 10 000 KVA, 11 000 volts, 50 cycles, with ± 8 steps each for 1.1 %, with hand operating gear.

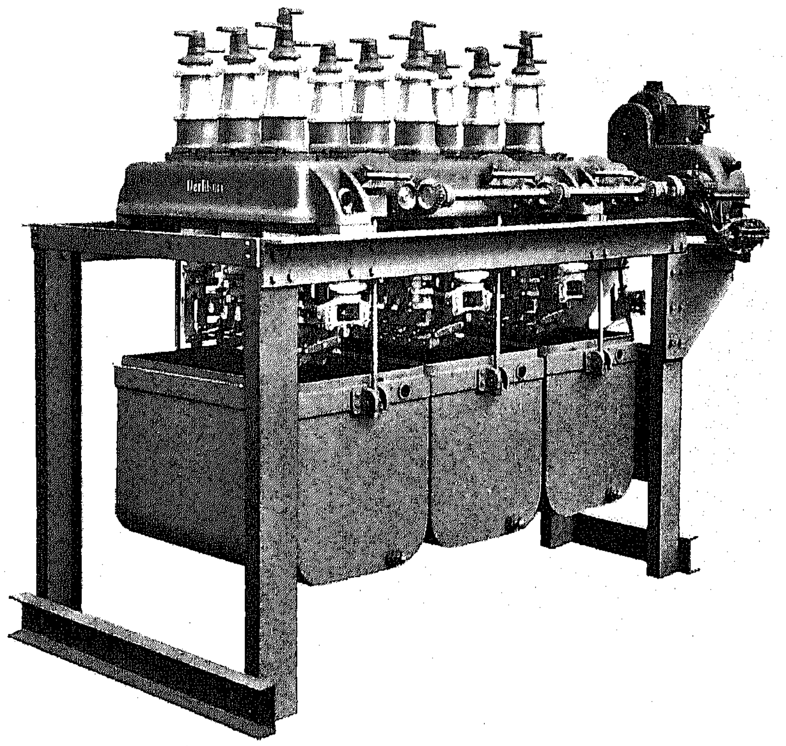


Fig. 17. Three-phase step-switch of the oil-immersed type, for a transformer for 13 500 KVA, 28 500 volts, 50 cycles, with 8 steps each for 1 %, with remote control.

In the field of traction, the step-switch has successfully held its place, in spite of the developments in connection with induction regulators, different modes of connection being used, which are always based on one of the two fundamental diagrams given in Figs. 4 or 6. In the case of the step-switches which work on the lines indicated in Fig. 4, the subdivision in tapping switches operated with current cut off, and circuit breakers for interrupting the load, is retained. The step-switches, based on the diagram in Fig. 6, on the other hand, are often in the form of individual single-pole switching elements called contactors, which are built in such a way that they themselves can interrupt the current. These contactors are operated either individually by electro-magnetic or pneumatic means, or through the intermediary of a common shaft by cams; a first arrangement derived directly from the fundamental diagram is that shown in Fig. 7. There are, for each tapping, two contactors. If the

into two streams gives rise to a certain ohmic drop and to permanent losses, in the positions where the choking coil is short-circuited. This can be obviated by inserting a further contactor and by short-circuiting, for the time being, only half the choking coil, as shown in the diagram in Fig. 9. The number of contactors amounts then to $\left(\frac{n-1}{2}+3\right)$ for n pressure steps (= positions of the step-switch).

In the case of all transformers where the portion of the winding which carries the tappings is designed as an actual regulating winding, distributed over the whole length of the limb, use can be made with advantage of a reversing arrangement. The regulating winding is then connected to the main winding in such a way that the pressure produced in it is added to or subtracted from the pressure of the main winding, according to the step pressure required. This reversal necessitates, as can be seen from the diagram

in Fig. 10, three more contactors than in the case of a fixed additional winding. In view of this, the number of pressure steps is doubled for the same number of tappings on the transformer. In the case of n pressure steps (= positions of the step-switch), it is necessary to have $\left(\frac{n-1}{4}+6\right)$ contactors for $\left(\frac{n-1}{4}+2\right)$ tappings on the transformer.

With a view to meeting this renewed demand for step-switches for pressure regulation on load, the Oerlikon Company have utilised the experience gained in connection with traction gear and evolved various types of apparatus of very substantial construction and reliable design. When the transformer pressures are low and the step pressures moderate, and when the gear is for indoor mounting, the step switches can be designed with advantage as air-break switches. Figs. 11, 12, 14 and 15 give examples of such step-switches. Figs. 11 and 12 show a single-phase step-switch and Fig. 14 a three-phase step-switch, with hand operating gear. The three-phase switch in Fig. 15 is provided with motor remote control. The contacts are built in the form of strong finger contacts or block contacts. The upper contact is fixed, while the lower one is fitted to a lever through the intermediary of springs, the lever being operated from the common shaft through the intermediary of cams, levers with rollers and insulating rods, arranged in a vertical plane. The step-switch is opened through the action of springs, assisted by the weight of the rods. If, for unforeseen reasons the contactor should not be opened by the springs, it is thrown open by special noses on the cams as the operating spindle revolves further. The moving contact has, when opening or closing, in addition to the main motion about the centre point of the lever, an additional motion about another point, chosen in such a way that the contact surfaces roll over each other, so that the passage of current does not take place at the same point during continuous service and during the interruption process. The burning of contacts cannot, therefore, disturb the passage of current during normal service. Fig. 11 shows the contacts of the first contactor and their horns, the arc chutes being removed. The blow-out coil is secured above the contacts; it carries a removable arc chute through the intermediary of pole plates. The switch is actuated in the case of hand operation, by a hand-wheel, through gears with stop and position indicator.

The type of step-switch described can be mounted very conveniently on the transformer, especially in the case of air-cooled transformers. Fig. 18 shows a 4130 KVA single-phase transformer with built-on step-switch for feeding furnaces.

In the case of high step pressures and step outputs, the step-switch is immersed in oil. In this case, the contact gear remains the same. The blow-out coils and arc chutes are alone dispensed with; the general assembly is the same as for oil circuit breakers, that is to say, the arrangement is the reverse of that for air break switches, the base being used as cover. Fig. 16 shows a three-phase oil-immersed step-switch with hand operating gear. Fig. 17 represents a switch with motor remote control. In the case of either type, the base-plate, that is to say, the cover is common for all three phases, while each phase has its own oil tank.

In the case of outdoor mounting the step-switch, like the corresponding transformer must, of course, be of the oil-immersed type. Fig. 19 shows a specially suitable arrangement (Patent applied for). The base of the switch is in the same plane as the cover of the transformer. The connections from the transformer to the step-switch are, however, not arranged externally, but are run in a prismatic container, where they are immersed in oil. The latter is above both the step-switch and the transformer cover, and serves, at the same time, as oil expansion vessel for the transformer.

The tanks of the three phases of the step-switch can be lowered individually for the inspection of contacts. The bridging coil is arranged inside the transformer tank. The transformer itself is secured in the ordinary way to the cover. When lifting the transformer out of the tank, the bridging coil, as well as the step-switch are raised at the same time. The connections between transformer and step-switch are directly uncovered once the cover of the oil expansion ves-

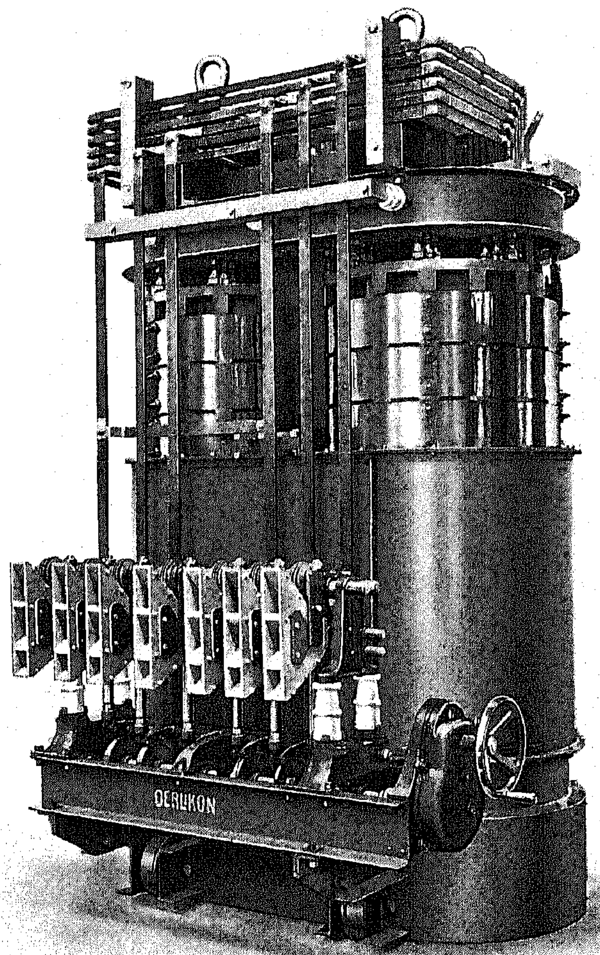


Fig. 18. Step-switch represented in Fig. 12, assembled with its transformer.

sel has been removed. The motor remote control equipment is arranged in a water-tight casing, the position of the step-switch being indicated outside. A handle is inserted for operation by hand and in order to prevent the possibility of simultaneous operation of the remote control equipment from the control room by means of a master switch, the control circuit is interrupted automatically.

Fig. 15 is a view of the moving contact of a contactor unit, showing the handle and pivoting point, the contact spring and the switching-off spring, as well as the operating rod of insulating material. In the case of high pressures, from 50000 volts onwards, the question of insulation becomes a primary consideration for step-switches too. It is, therefore, necessary to find a design where the insulation

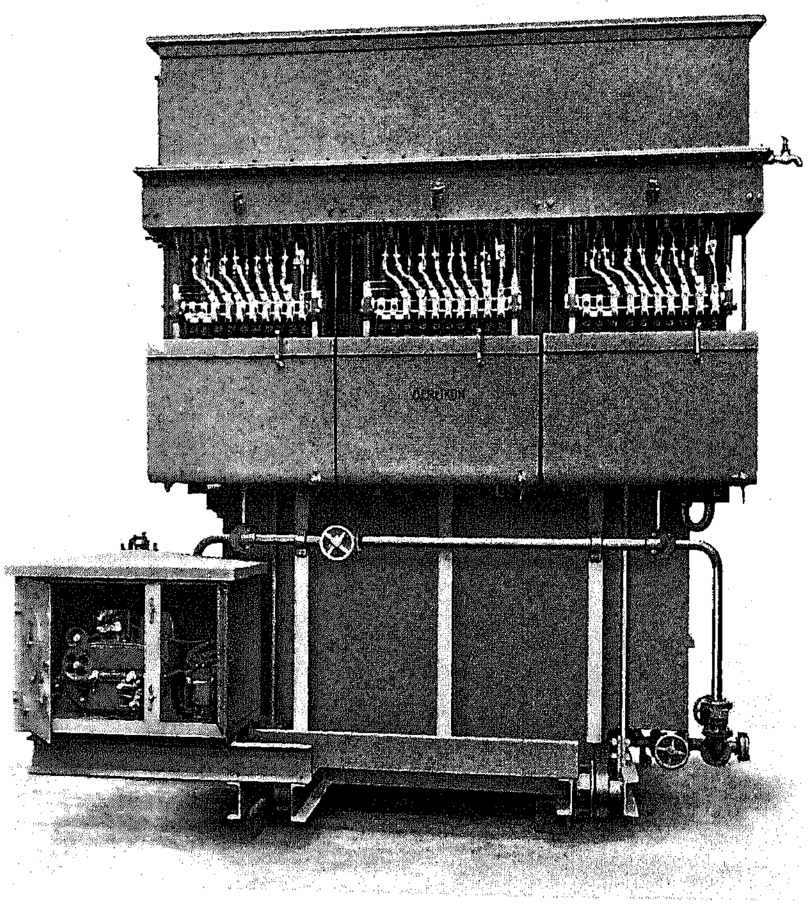


Fig. 19. Three-phase regulating transformer for 8000 KVA, 16500 volts, with built-on step-switch of the oil-immersed type, with ± 10 steps each for 1 %, for outdoor mounting. Step-switch with remote control; the oil tank is lowered and the operation box open.

to earth is, as far as possible, concentrated at one point. In view of this, the step-switch has been sub-divided once more, as in the case of the fundamental diagram in Fig. 6, into two parts: the tapping switch for operation with the current cut off, and the actual circuit breaker. This step-switch was, from the very beginning, only designed for mounting on the corresponding transformer; it consists, as can be seen from Fig. 20, of two separate tanks for each phase. The upper one is mounted on the transformer and contains the tapping switch; this switch is built as a drum

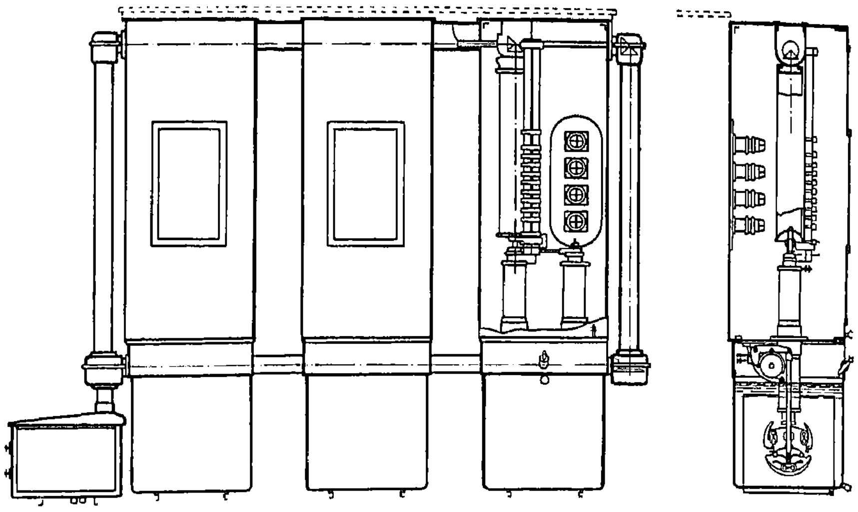


Fig. 20. Step-switch for a three-phase regulating transformer for 10 000 KVA, 52000 volts, 50 cycles, with 16 steps each for 1.2 %, for outdoor mounting and with remote control.

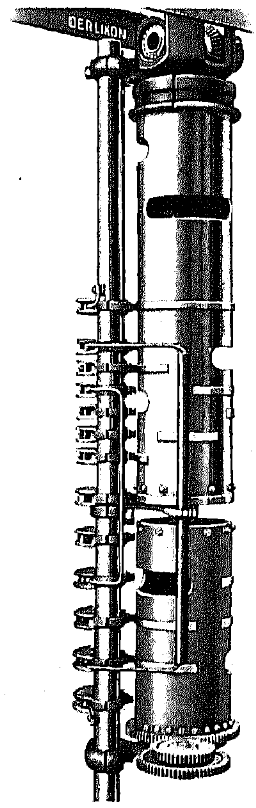


Fig. 21. Tapping switch of a step-switch for 62 000 volts.

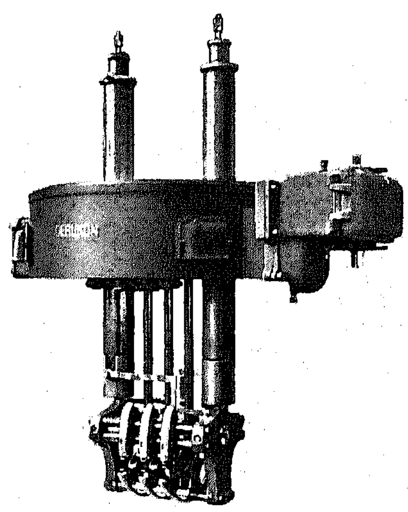


Fig. 22. Circuit breaker of a step-switch for 62 000 volts, without its oil tank.

type switch. The drum is in the form of an insulated tube, of which the upper extension provides the insulation against the earthed operating gear (see Fig. 21). In order to be able to dispense entirely with insulation at the other end, the drum is fitted to one of the bushings leading to the circuit breaker. The circuit breaker itself is arranged below the tapping switch so that the base of the latter constitutes its cover.

These tapping switches too are of very substantial construction, both as regards contacts and operating gear, so that great reliability in operation is ensured. A point to which special attention has also been paid is that all parts requiring some maintenance should be easily accessible. The tanks of the circuit breakers can be lowered through the intermediary of spindles operated by handles, as in the case of ordinary oil circuit breakers. The contacts (Fig. 22) are then entirely uncovered. The circuit breakers are designed for instantaneous double interruption. The drums of the tapping switches can be easily inspected once the front of the upper tank of switch has been removed.

Fig. 23 represents a three-phase transformer for 10 000 KVA, 52 000 volts, with built-on step-switch, with 16 steps each for 1.2 %. The bridging coil is, in this case too, arranged in the tank of the transformer. Fig. 24 shows another design where the choking coil is fitted in the tank of the tapping switch. For this reason, the terminal which serves for connecting up the neutral point of the bridging coil to the outgoing line is also mounted on the cover of the tapping switch.

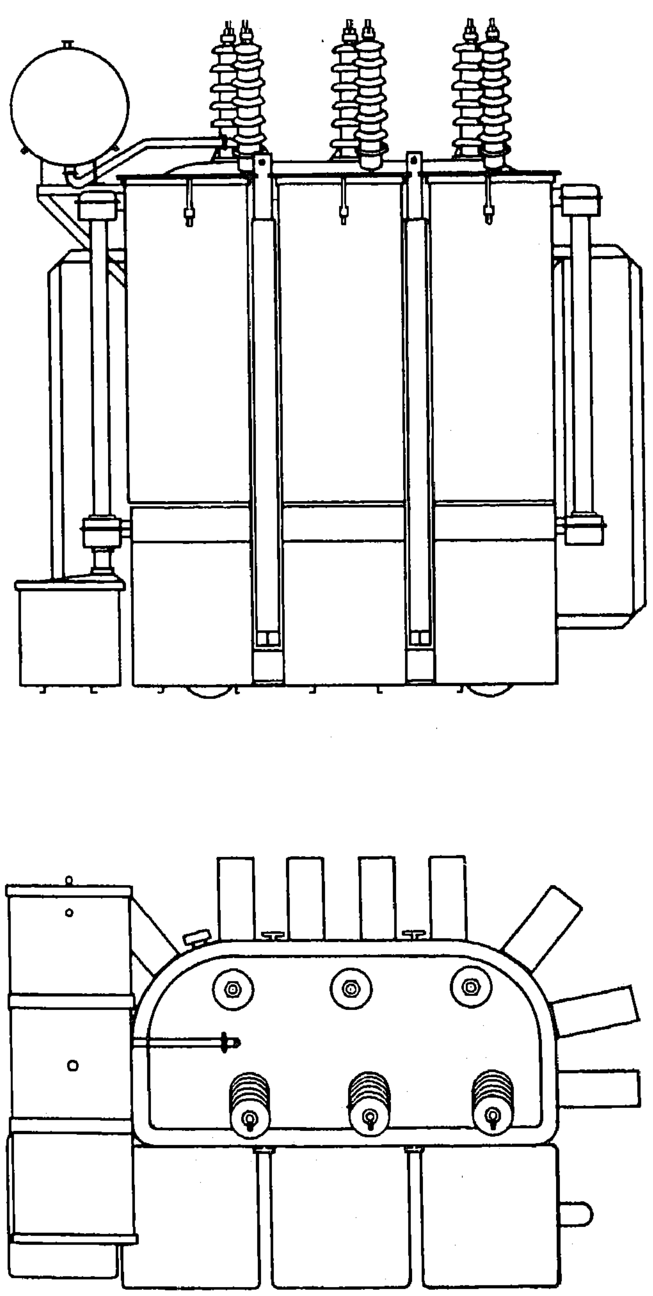


Fig. 23. Step-switch represented in Fig. 20, assembled with its transformer.

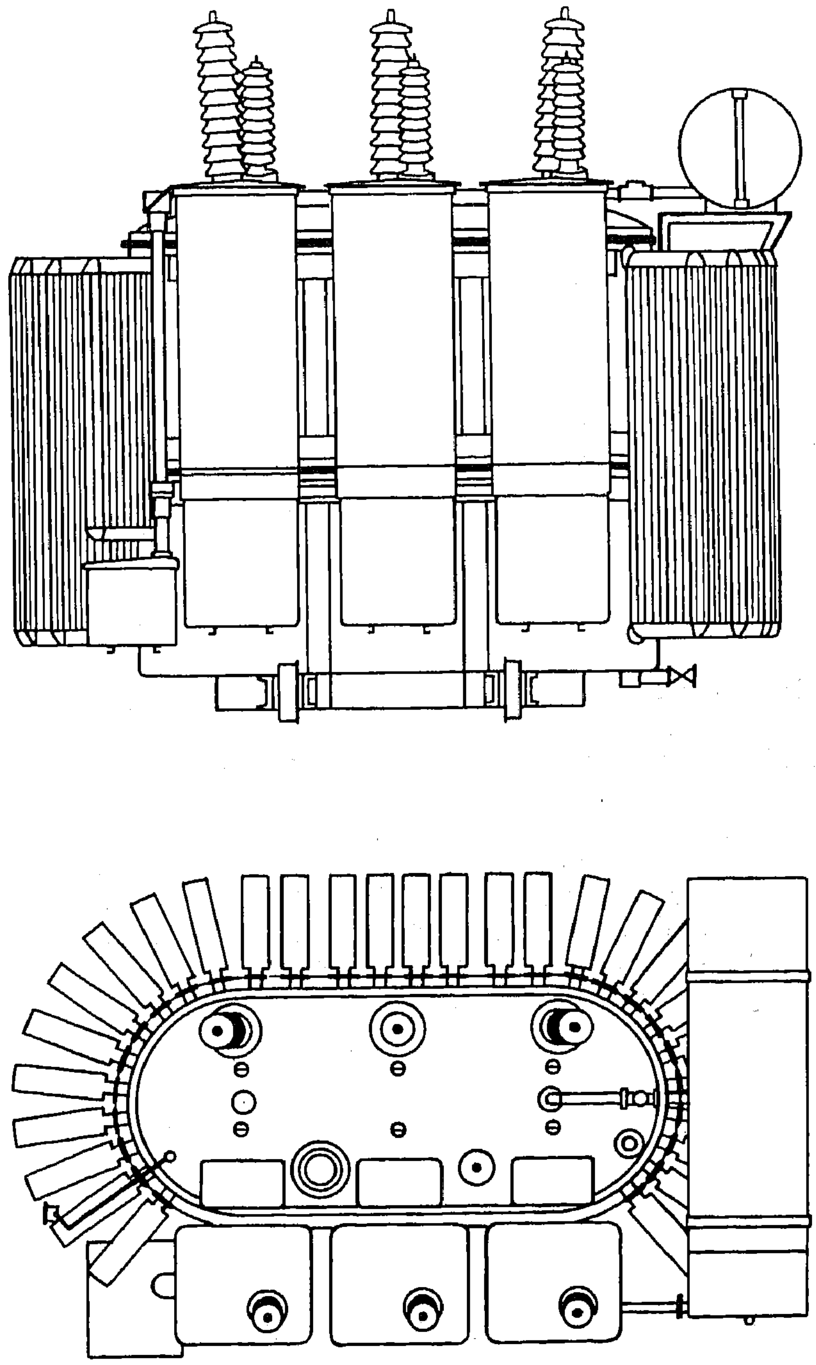
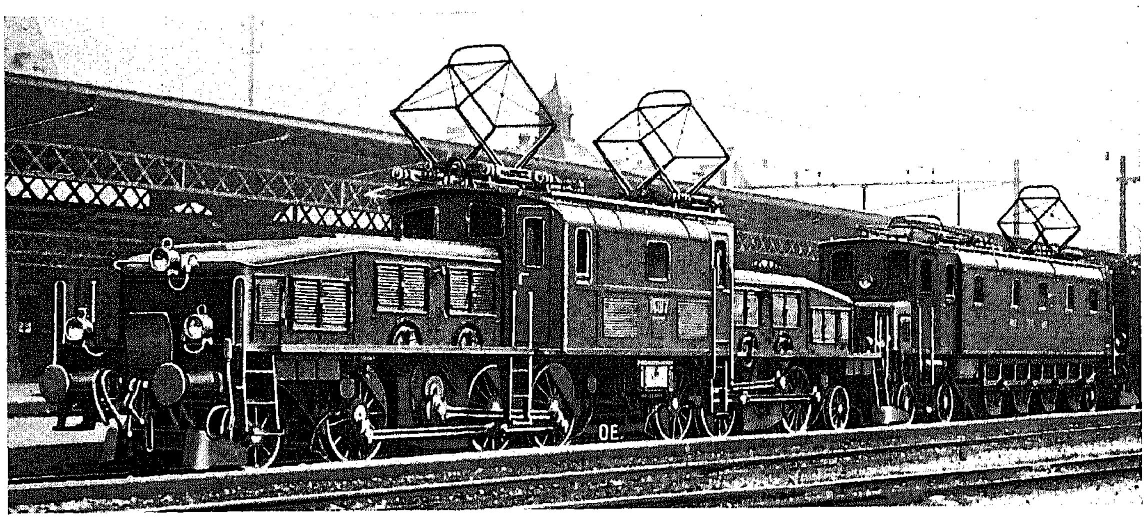


Fig. 24. Three-phase regulating transformer for 10 000 KVA, 62 575 volts, 50 cycles, with built-on step-switch of the oil-immersed type, with 10 steps each for 2 %.

On the Behaviour of the Commutators of the Driving Motors of the Oerlikon Single-Phase Locomotives

Series Ce $^6/_8$ III (1 CC 1) and Ae $^4/_7$ ($2D_01$) supplied to the Swiss Federal Railways.

In the early days of main line traction with single-phase locomotives, the commutators of the motors were regarded, in a general way, as one of the most sensitive parts of the electric locomotives. There was no doubt some reason for this as, with certain types of motors, it was not infrequent that the commutators required to be overhauled after mileages of only 4000 to 5000 locomotive-miles. Such conditions must be ascribed, in greater part, to the difficulties connected with the construction of commutators with comparatively large number of segments and a small width of segment; these difficulties were further accentuated by the fact that the commutators of locomotive motors are, as a rule, subjected to great variations in temperature. Deformations usually occurred in the commutators after longer or shorter periods of operation. Once these deformations had taken place, this had a detrimental effect on the working of the brushes, especially at high speeds, with the result that the commutator surface too was affected and had soon to be turned down or ground.



1 CC1 and $2D_01$-Locomotives at the Oerlikon Station.

Even after the great improvements, in the course of years, in the appliances for smoothing the commutators, which made it, for instance, no longer necessary to remove the motors for carrying out this work, these operations meant, nevertheless, a longer or shorter idle period for the locomotives, as, apart from reconditioning the commutator surface, it was also necessary, in most cases, to cut down the insulation between commutator segments.

For this reason, the Oerlikon Company have spared neither efforts nor funds with a view to finding means and ways of improving these conditions to the utmost degree. These efforts have been entirely successful and it may, therefore, be of interest to describe the results obtained, at the present day, with the commutators of the motors of the Oerlikon locomotives. There is a regulation in Switzerland that locomotives must undergo a general overhaul after periods of service of 3 years at the most. When this general overhaul takes place, the locomotives are completely dismantled and all the worn-out parts are either reconditioned or replaced. The Oerlikon Company have, therefore, tried to improve the design of commutators, or the conditions under which they work, to such an extent that there should be no need for any work on the commutators between general overhauls, that is to say, for a period of 3 years.

This condition, which seemed impossible to satisfy some 5 years ago, has at the present day not only been fulfilled, in the case of Oerlikon traction motors, as a result of active collaboration of all parties concerned, but has even been improved upon, in certain cases.

We now propose to give, in connection with the above, a few data regarding the actual results obtained with commutators. Mention can be made, in first place, of the freight locomotives, series Ce $^6/_8$ III (1-C-C-1) of the Swiss Federal Railways (see Oerlikon Bulletin No. 43, January 1925), some of which have been running, without any subsequent work being required on the commutators, ever since they were put into service, that is to say, for 3 to $3^3/_4$ years. During that time, one locomotive has covered a mileage of about 287,000 locomotive-miles.

Other locomotives recently built are the express locomotives, series Ae $^4/_7$ (2-D_0-1) (see Oerlikon Bulletin No. 97, July 1929), supplied to the Swiss Federal Railways in 1928.

Up to the end of October 1930, the first of these locomotives had covered, since being put into service (October 1928), a mileage of about 187,000 locomotive-miles, also without any work being required on the commutators, subsequently. It may be anticipated, with certainty, from the appearance of the commutator surface of these motors, that as high a mileage will be obtained with these motors as in the case of the motors of the above-mentioned locomotives, series Ce $^6/_8$ III.

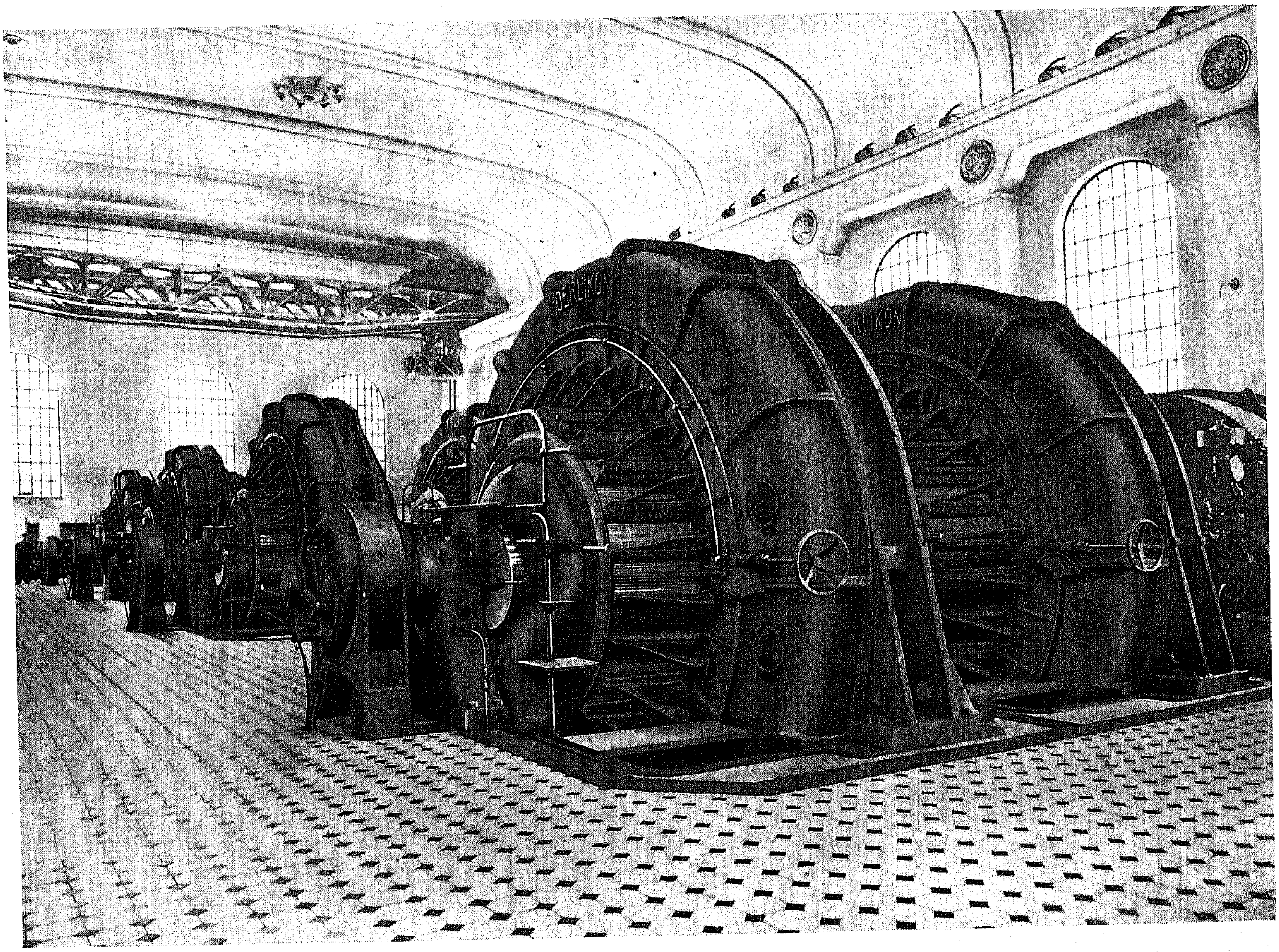
When comparing these figures with those published in foreign technical papers, specially in German publications, it is necessary to bear in mind that the former refer to the mileage in locomotive-miles while, in Germany, it is nearly always the practice to give them in commutator-kilometres, corresponding to commutator-miles. In the case of the Oerlikon locomotives Ce $^6/_8$ III, the above value of 287,000 locomotive-miles is equivalent to about 595,000 commutator-miles, while the mileage of 187,000 locomotive-miles, for the commutators of the Oerlikon locomotives Ae $^4/_7$, is equal to about 254,000 commutator-miles,

From the figures we have given, it is clear that a commutator which is correctly designed and carefully assembled can no longer be regarded as a more delicate part of the locomotive than any component part of the rest of the electrical equipment or even of the mechanical part.

BULLETIN OERLIKON

No. 116 — February 1931

Contents: The generating plant of Vemork of the A. S. Ryukanfos.
H. T. plant for testing insulation and charging cables.
Diesel-electric locomotives and motor coaches.
Notes and News Items: Performance of Oerlikon locomotives.



GENERATING PLANT OF VEMORK OF THE A. S. RYUKANFOS, WITH 4 UNITS OF 12000 K.W. EACH.

Each of the two D. C. Generators of the above groups has an output of 12000 amps. at a pressure of 470—540 volts (6000 K. W.). Speed:— 250 revolutions per minute.

H. T. Plant for Testing Insulation and Charging Cables.

One of the special types of equipments included within the range of manufacture of the Oerlikon Company, which deserves particular mention, is their H. T. testing plant. Equipments of this description were supplied by them as far back as the earliest days of industrial application of high tension, and the experience gained in the course of many years, in connection with most varied installations, has furnished valuable data for the designing and the operation of new plant.

The principal component part of an H. T. testing equipment is, of course, the step-up transformer or transformers and the insulation of this plant often presents difficult problems. The transformer equipment consists either of a single transformer giving, on the secondary side, the total pressure required, or of several cascade-connected transformers, this being dependent upon the output and the pressure it is desired to obtain and upon the mode of connection adopted. In view of the rather high pressure drop of these transformers, it is advisable not to take too low a capacity, specially in the case of very high pressures, as, on the one hand, the capacity of the whole installation itself is no longer negligible and, on the other hand, when arcing takes place on the object which is being tested, the pressure drop at the terminals is all the greater if the power available is small.

While the question of the shape of the pressure curve may be of secondary importance for tests of short duration, this is no longer the case for prolonged tests, as when charging cables. It is then necessary to have, even on the secondary side, that is to say on the H. T. side of the transformer, a wave curve approximating as nearly as possible a sine curve, and to eliminate all causes such as may lead to a deformation of that curve or, what is equivalent, to the introduction of higher harmonics, of which the amplitude may increase to multiples of their value, as soon as the transformer works on appreciable capacities.

The deformations of the pressure curve can be due either to the transformer or to the intermediate gear. In view of this, the plant should not be connected directly to a section of the distribution system, as the pressure in such a section usually differs considerably from a sine curve. Furthermore, the pressure curve is subjected to sudden deformations when switching operations take place in the system. It is also necessary to avoid the use of an intermediate induction regulator which apparatus, owing to its teeth and magnetic saturation, can only increase the deformations and cause new ones. The supply must, therefore, be derived from an alternator producing a perfectly sinusoidal curve. As regards the transformer, the influence of its saturation on the pressure curve is reduced as far as possible by limiting its value.

It is not advisable to use ordinary alternators with salient poles, as this type of machine can only give satisfaction within restricted limits. The addition of damper windings is incapable of correcting, in an effective manner, the influence of higher harmonics, even when the damper windings are very amply dimensioned. In view of this, the Oerlikon Company have made a thorough study of the question and built an alternator of special design, which has given very good results for many years, in the case of the various machines supplied for testing equipments. The rotor of this alternator and also the stator are built up of laminated steel. The field winding is distributed over

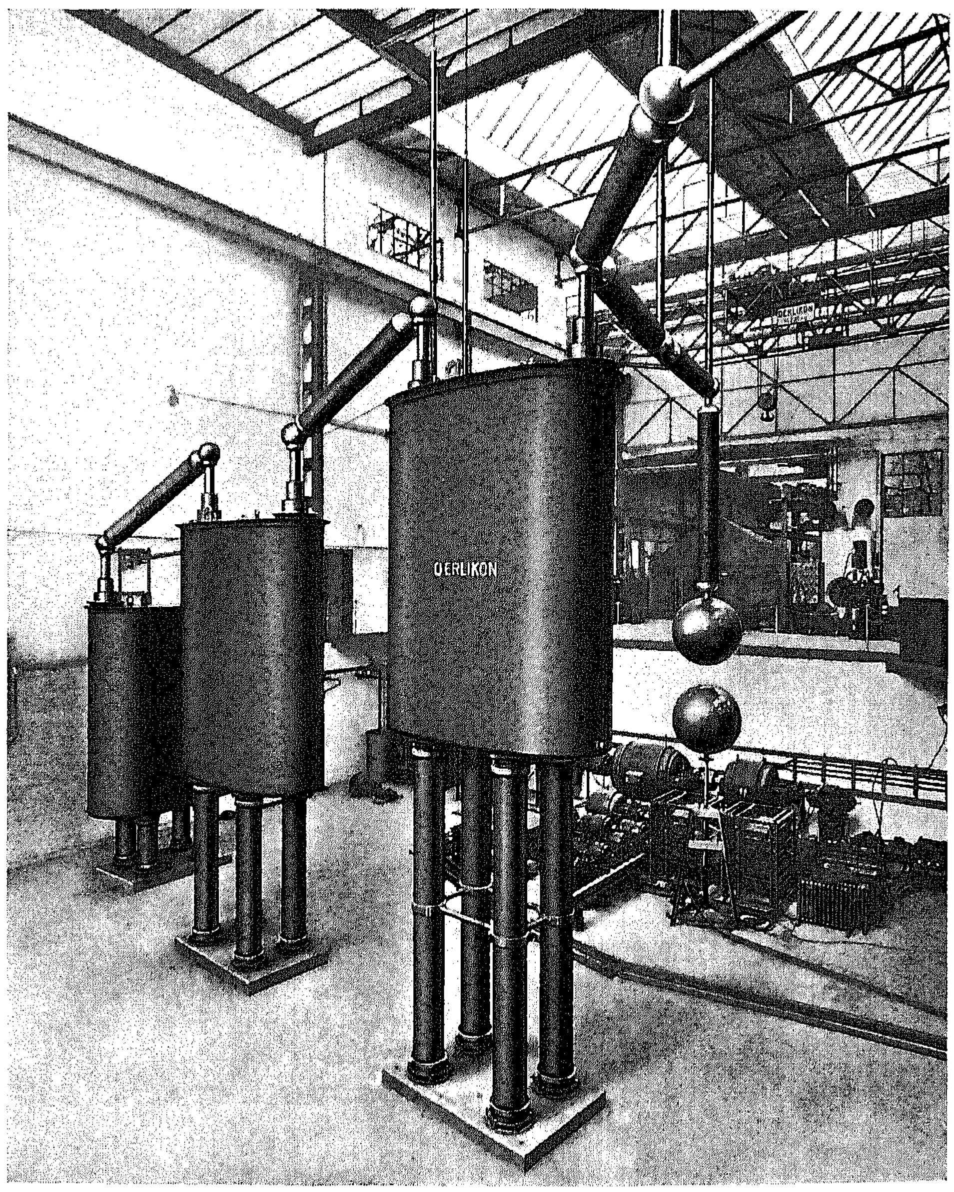


Fig. 1. Testing equipment for 1 000 000 volts at the Oerlikon Works.

the whole periphery of the rotor, which is, furthermore, provided with a damper winding in the shape of a squirrel cage. The higher harmonics are further reduced by suitably designing the windings and the slots. In this way, it is possible to obtain pressure curves which depart from the corresponding sine curves only in an imperceptible manner, that is to say, to a smaller degree than the degree of precision of the standard oscillographs.

There is, of course, no objection to the supply being derived from a distribution system, either directly or through the intermediary of an induction regulator, when the tests are of short duration, and in installations where great stress is not laid upon the shape of the pressure curve.

When the H. T. testing plant is intended for the testing of gear with a high capacity, such as cables, condensers, it is permissible not to design the alternator (or the induction regulator) for the full capacity of the transformer. The larger part of the capacity current is then compensated by means of adjustable or non-adjustable reactance coils inserted on the primary side of the transformer. The output of the alternator is, in this case, fixed by the amount of power which has to be supplied to the transformer and to the reactance coils for covering their losses as well as for satisfying the conditions as regards stability (auto-excitation).

As instances of some of the most recent and important testing equipments built by the Oerlikon Company, mention can be made of the 1 000 000 volt plant, installed at their Works to meet their own requirements, and the 200 000 volt equipment for charging cables, supplied to the Société d'Exploitation des Câbles Electriques Système Berthoud, Borel & Cie., at Cortaillod, in Switzerland.

The former equipment is represented in Fig. 1; it comprises a set of three cascade-connected transformers mounted on insulated supports, with a total capacity of 1200 KVA, one of the poles of the set of transformers being connected to earth. The apparatus to be tested can thus be put immediately under tension, without having to insert an insulating platform. A tank of large dimensions and out of which the air can be exhausted is provided for the testing of insulating material in oil. The pressure is measured by means of a static voltmeter with spheres 1000 mm in diameter, the tolerance allowed on the diameter being 1 ‰. The alternator, which is also to be suitable for use with other testing equipments, has a capacity of 360 KVA; it is direct coupled to a 320 HP. synchronous induction motor. The compensating current is supplied by two reactance coils, one of which is adjustable and remote controlled by means of servo-motor. The control operations for the tests are carried out from a switch desk, which is provided with a supervisory diagram with pilot lamps and miniature switches. A panel arranged near the oil tank duplicates the control.

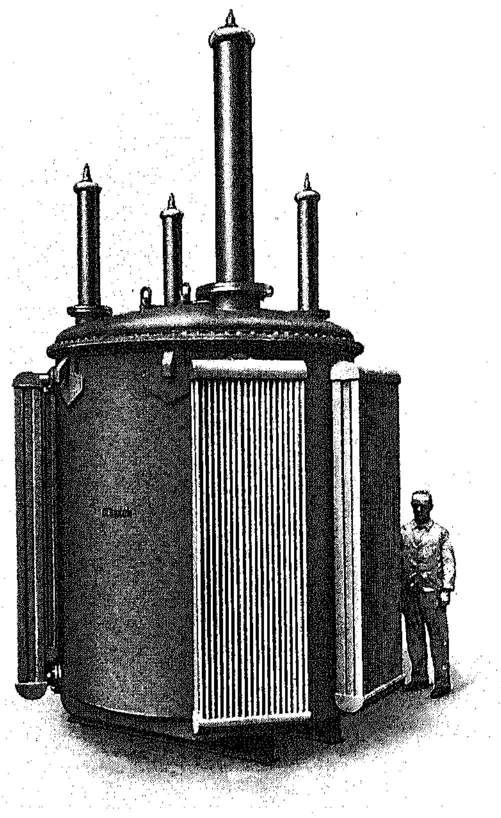


Fig. 2. Transformer for 200 000 volts for charging cables.

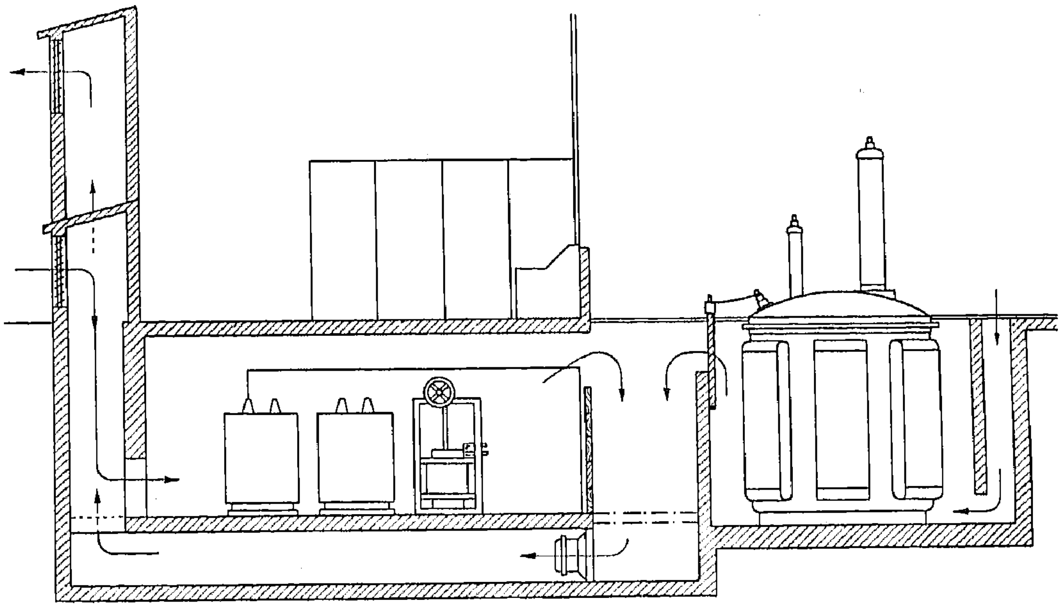


Fig. 3. General arrangement of the plant for 200 000 volts for charging cables.

The second equipment, supplied to the Société d'Exploitation des Câbles Electriques, Système Berthoud, Borel & Cie., is intended for carrying out continuous pressure tests on drums of cable; there is, therefore, in this case a heavy capacity load. The pressure is derived from a single transformer with an earthed pole; the secondary winding of the transformer can be connected either in series or in parallel, so as to obtain the full output of 1200 KVA, both at 200 000 volts and at 100 000 volts. Before this plant left the Oerlikon Works, it was subjected to a pressure of 400 000 volts applied for five minutes and derived from the

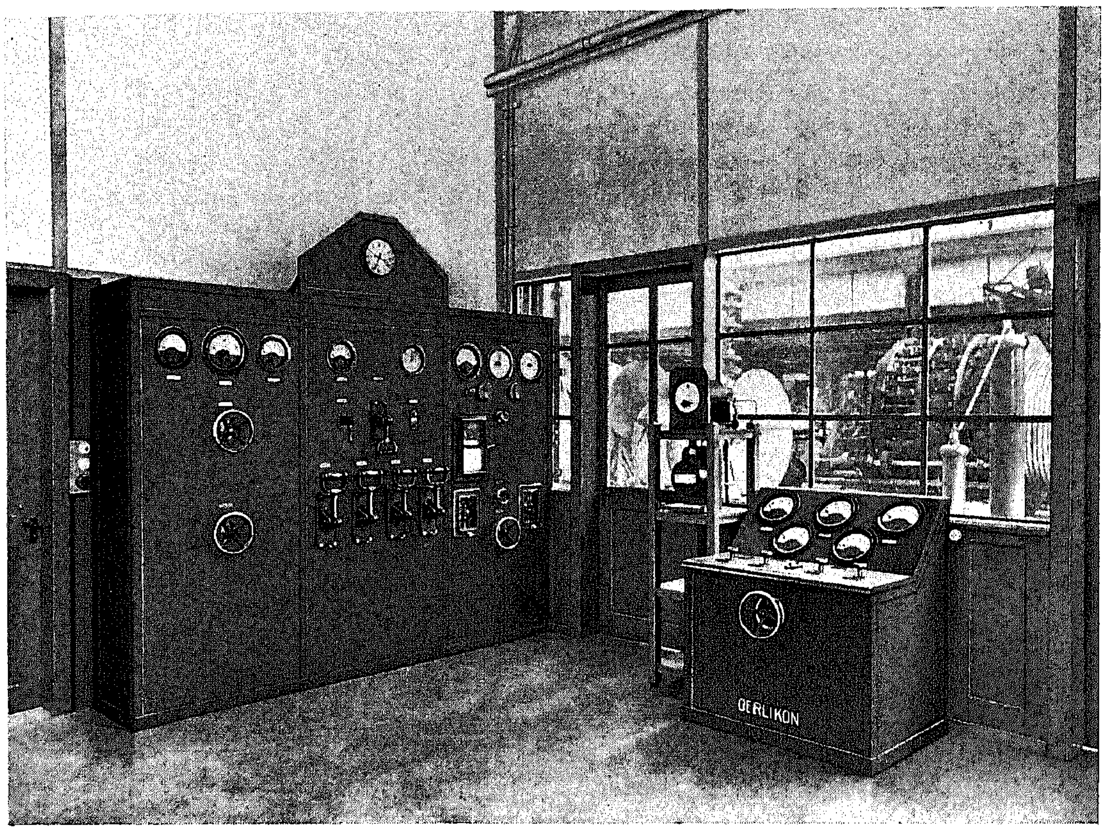


Fig. 5. Control room of the installation for 200 000 volts for charging cables.

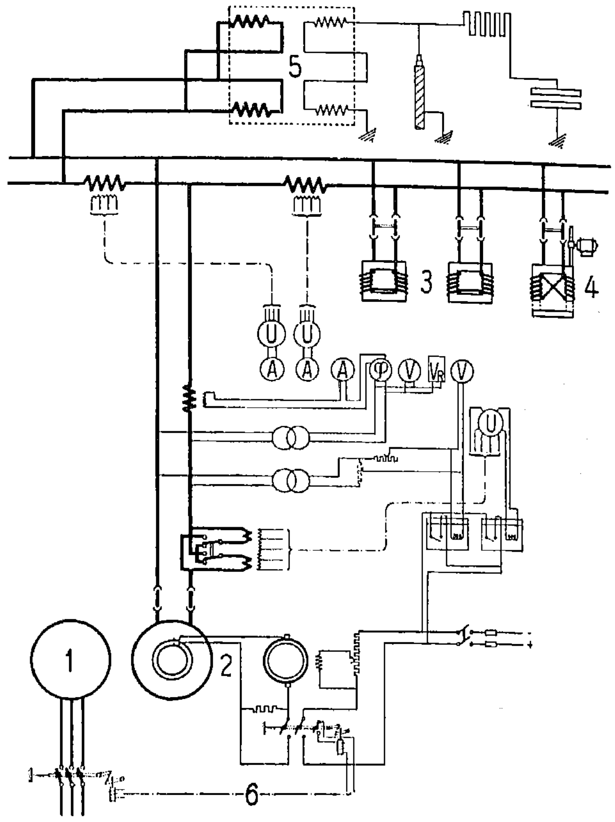


Fig. 4. Diagram of connections of the installation for 200 000 volts for charging cables.

1 Synchronous induction motor with exciter
2 Single-phase alternator with exciter
3 Non-adjustable reactances
4 Adjustable reactance
5 Testing transformer
6 Combined tripping device

transformer itself. Although the transformer is a testing transformer for 200 000 volts, it complies with the regulations of the V. D. E. *) for ordinary static transformers intended for continuous operation at 200 000 volts.

The alternator has, in this case too, a capacity of 360 KVA, and its motor is also a synchronous induction motor; the latter has an output of 110 KW. and serves, at the same time, for compensating the wattless load of the internal distribution system of the Works. The reactances for compensating the capacity current are sub-divided into three units, one adjustable and two non-adjustable.

The question of the arrangement of the whole equipment has been carefully studied, the object aimed at being to ensure ready access to the plant, and easy control and supervision.

The transformer is arranged in a pit in such a way that its cover is flush with the floor of the cable room. The whole control gear and all the instruments are grouped on a switch desk and a panel in the control room, the alternator and the reactance coils being arranged under the latter.

As further equipment, we may also mention the testing plant for 750 000 volts (Fig. 6) supplied, in 1926, by the Oerlikon Company to the Université Libre de Bruxelles (see Bulletin Oerlikon No. 58).

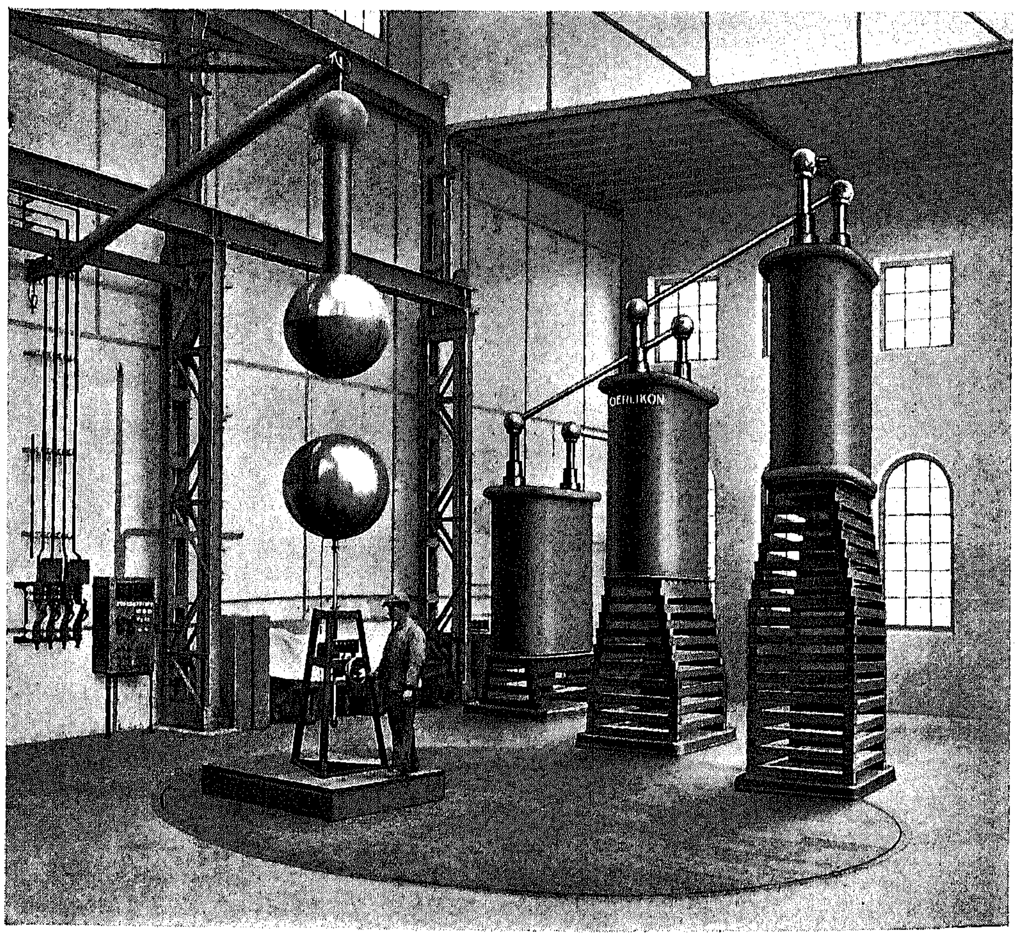


Fig. 6. Testing plant for 750 000 volts.

*) Association of German Electrical Engineers.

Diesel-Electric Locomotives and Motor Coaches.

The first attempts to use Diesel engines for traction purposes on locomotives, dates some twenty years back, this plant having been utilised even before then for the propulsion of ships. The earliest tests with locomotives equipped with Diesel engines were carried out in Germany, the native country of the inventor of the engine, Dr. Diesel, in which connection the Swiss industry played a leading part, as Messrs. Sulzer Bros, in conjunction with the Borsig Locomotive Works, built a passenger train locomotive with Diesel engine of the Sulzer type for the trials.

In the case of the first designs of Diesel locomotives, the power was transmitted from the Diesel engine to the driving wheels by purely mechanical means such as, for instance, the so-called Lentz oil pressure gears or the gears of the Swiss Locomotive Works of Winterthur, of Messrs. Schwartzkopff-Huwiler and of other makes. Furthermore, gears utilising compressed air were also tried, while a design with mechanical transmission by means of bevel gears and electro-mechanical coupling was evolved by the Nuremberg Machine Works in collaboration with the Esslingen Machine Works, this design being based upon the data of Prof. Lomonosoff. This firm built also a 1200 HP. Diesel locomotive with electric transmission which is known, in the technical literature, as the „Lomonosoff locomotive". In this connection, it may be mentioned that the Oerlikon Company made in 1915, in conjunction with Messrs. Sulzer Bros. exhaustive studies with regard to a 2000 HP. Diesel locomotive for Russia; the locomotive, however, never reached the manufacturing stage, owing to the war. Fig. 1 represents the double generator such as designed for this locomotive. Space does not permit us to mention here all the early designs of Diesel locomotives evolved in Germany, England,

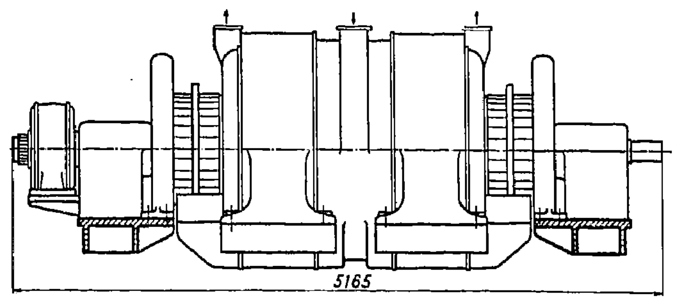


Fig. 1. Proposed design of a double generator for a 2000 HP. Diesel-electric locomotive such as put forward by the Oerlikon Company in 1915.

Scandinavia, America and other countries. This subject of the historical development of the Diesel locomotive is fully dealt with in the excellent work by Prof. Lomonosoff, published in 1929.

There are still at the present day differences of opinion between engineers with regard to the question as to which mode of transmission should be adopted between Diesel engine shaft and driving axles. The translator of the work referred to above, Prof. Meineke, Dr. Eng., is of opinion that Diesel locomotives for main line service should be built with gear wheel transmission. It has, however, been decided otherwise in practice, as practically all modern Diesel locomotives are built with electric transmission.

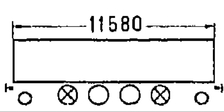
We give below a list of Diesel-electric locomotives fitted with electrical equipments built either entirely or partly (Buenos Aires-Gt. Southern Railway) b ythe Oerlikon Company. Before passing to the description of individual designs and more especially of those fitted with Oerlikon electric equipment, we propose to examine a few fundamental arrangements that are possible for electric transmission.

In the case of Diesel-electric locomotives, the principle underlying the design, is to arrange for the Diesel motor or motors to drive one or several direct coupled D. C. ge-

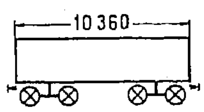
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Diesel-Electric Locomotives and Motor Coaches with Oerlikon Electric Equipments, supplied during the years 1929—1931.

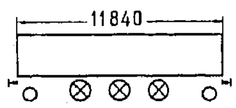
1929 Two Locomotives for passenger trains, 2 × 600 HP. each *). BUENOS AIRES - GREAT SOUTHERN RAILWAY. (only generators and auxiliaries supplied by the Oerlikon Company)



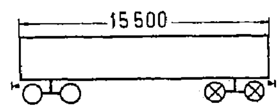
1929 One Motor Coach for passenger trains, 450 HP.*) BUENOS AIRES - GREAT SOUTHERN RAILWAY. (only generator and auxiliaries supplied by the Oerlikon Company)



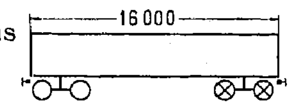
1929 One Locomotive for shunting purposes with oil drive, 600 HP.*) BUENOS AIRES - GREAT SOUTHERN RAILWAY. (only auxiliaries supplied by the Oerlikon Company)



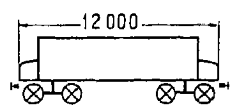
1929 Two Motor Coaches for passenger trains, 250 HP. each.*) APPENZELL RAILWAY.



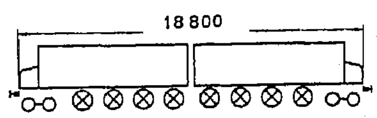
1930 One Freight Motor Coach for passenger trains and mixed service, 420 HP.*) SWISS FEDERAL RAILWAYS.



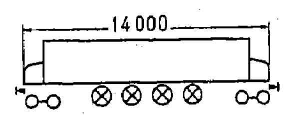
1930 One Locomotive for freight trains and shunting purposes, 750 HP.*) SOUTH MANCHURIAN RAILWAYS.



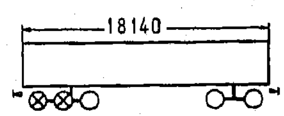
1931 One Double Locomotive for freight and passenger trains. ROYAL SIAMESE RAILWAYS. 2 × 700 HP. †)



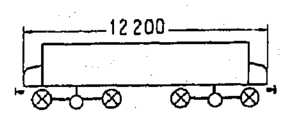
1931 Six Locomotives for express trains, 2 × 450 HP. each. †) ROYAL SIAMESE RAILWAYS.



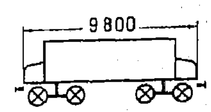
1931 Six Motor Coaches for suburban service, 150 HP. each.†) ROYAL SIAMESE RAILWAYS.



1931 Six Locomotives for freight trains and shunting purposes, 450 HP. each.*) ROYAL SIAMESE RAILWAYS.



1931 Three Locomotives for shunting purposes, 330 HP. each.*) PUERTO DE ROSARIO (Argentine Republic)



*) Output of the Sulzer Diesel engine.
†) Output of the Frichs Diesel engine.

⊗ Driving axles
○ Carrying axles

nerators. The generator, which is designed for separate excitation or with additional counter-compounding, transmits its energy to the traction motors, the regulation of the output and of the speed being ensured by regulating the generator pressure to suit the conditions of operation.

It may be assumed that it is a well-known fact that the all-important consideration, for Diesel locomotives, is that the output of the Diesel engine should be fully utilised, with a view to ensuring economical results in the matter of fuel consumption. In the case of railway operation, however, the tractive effort required to propel the train assumes values differing very considerably, according to the weight of the train, the gradient and the resistance of the curves, while, on the other hand, when running on level track, the power to be supplied by the Diesel engine varies according to the value of the speed and practically in the same ratio as the latter. As the Diesel engine can be overloaded only to a limited extent — about 10% — it would be overloaded to an excessive degree when coming to a gradient, if the train is run at constant speed.

The type of motor which is exclusively used in the field of traction in general and for Diesel locomotives with electric transmission, is the series wound motor. In view of this, the traction motor, owing to the shape of its characteristic, adapts itself automatically, in a certain measure, to the combustion engine. In the case of such a traction motor, there would still be an automatic variation of power of 1 to 3 when working within the permissible limits of speed and tractive effort.

The lines along which the various designers have proceeded, with a view to utilising as fully as possible the Diesel engine and its generator, and, on the other hand, the traction motors, by working at constant output, differ very considerably. Messrs. Beardmore, for instance, have sought to solve the problem by arranging for the variation of the power supply, by altering the speed of the Diesel motor alone, provision being made for three different speeds corresponding to the outputs required, which are obtained through the operation of the fuel governor handle. The pressure in the electric transmission system is thus subjected to three variations corresponding to the three speed steps. This method of regulation presents the advantage of great simplicity as regards attendance, as all that it is necessary to do is to displace the fuel governor handle and to watch the power meter. On the other hand, this mode of control has also disadvantages, as, when there are only three available pressures in the electric system, corresponding to the three speeds for which the Diesel engine can be adjusted, it is not possible to obtain a continuous full-load curve. It may also be mentioned that in the matter of speed of Diesel engines, Messrs. Beardmore go furthest, as they allow speeds up to 1200 RPM, though they now advocate lower figures. There is another mode of regulation for Diesel-electric locomotives, which is nearly of general use; it consists, as mentioned at the beginning, in separately exciting the generator coupled to the Diesel engine and in regulating its pressure within wide limits, corresponding to the requirements of the service; this, in itself, permits of a good approximation to the conditions aimed at as regards operation at constant output. Still better results are obtained by arranging for the counter-compounding of the generator field, as, in this way, the output curve of the Diesel engine for constant load can be made to approximate still further that of the traction motors (see Fig. 2).

In practice, however, it has been found that it is never possible, in the case of railway operation, to utilise fully, under all conditions, the output of the Diesel engine running at normal speed, whatever method may be adopted for automatic pressure regulation, as the train weight has to vary within wide limits, according to the conditions of

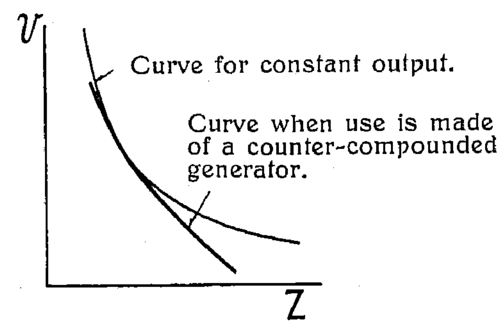


Fig. 2. Tractive effort-speed curves.

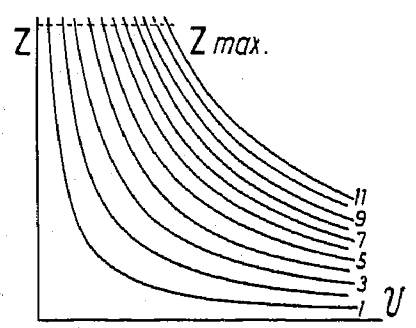


Fig. 4. Tractive effort-speed curves for the control arrangement shown in Fig. 3.

a = Regulator handle coupled to the fuel governor.
b = Contact for maximum admission.
c = Contact for minimum admission.
d and e = Reversing contacts for the servo-motor.
f = Controller.
g and h = Coils for the operation of the speed adjusting device of the Diesel engine.
i = Servo-motor.
k and s = Field coils of the servo-motor for forward and reverse operation.
n = Current limiting relay.
m = Closing relay.
o = Main generator.
r = Field of the main generator.
q = Field regulator.
p_1 and p_2 = Traction motors.

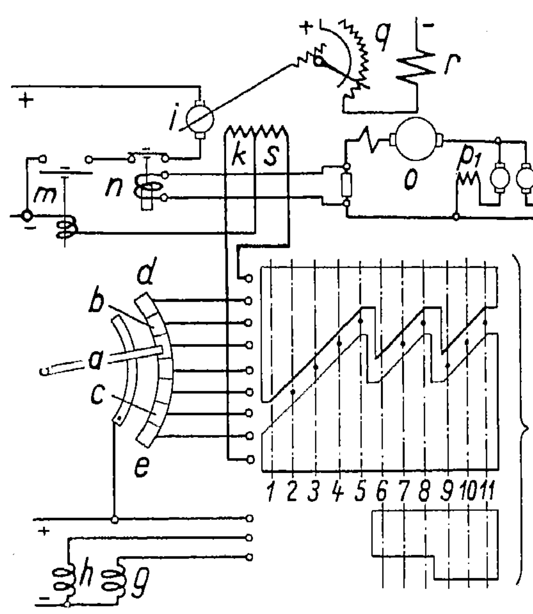


Fig. 3. Diagram showing the control arrangement combined with the operation of the fuel governor.

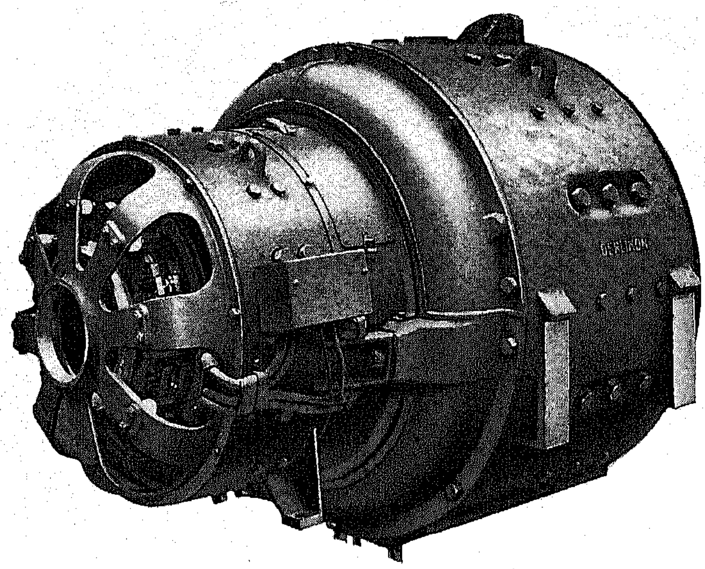


Fig. 5. Generator and exciter of the 750 HP. locomotive for the South Manchurian Railways.

service at the time. In the case of railways with great variations in gradient, in particular, it is not always possible to utilise fully the output of the Diesel engine, when the latter is run at constant speed. In such cases, a combination of the two methods of regulating the transmission system — regulation of the speed of the Diesel engine and, at the same time, automatic regulation of the pressure of the generator — is indicated. In practice, the way in which the problem has been solved has been to provide for the operation of the Diesel engine at two and, if necessary, three given speeds chosen so as to differ by the amount required to suit the conditions of service. The output of the Diesel engine then varies practically in the same ratio as the two or three speeds obtainable. The characteristic of the generator can be altered at each of these speeds, either automatically or by hand, so as to correspond to the requirements at the time; in this way, very economical operation can be ensured.

The Oerlikon Company have devised several such methods of regulation and have had them patented (for instance, Swiss Patent 138482). In the case of the latter mode of regulation, the regulator handle serving for the regulation of the pressure of the generator is controlled, while the locomotive is running, by a device which is operated by one of the axles of the locomotive so that, for instance, each speed of the locomotive corresponds to a given position of the regulator handle. The consideration underlying this method of automatic regulation is that, when the output of the Diesel engine is constant, there is a definite relation between the tractive effort at wheel rim, the generator current, the generator pressure and finally the excitation current of the generator. The excitation of the generator at a given speed is thus fixed. If the pressure regulator is, as mentioned above, controlled from the axles of the locomotive, the output of the Diesel engine can be kept constant over practically the whole range of regulation by providing the automatically controlled regulating resistance with suitable steps. The driver himself adjusts the Diesel engine for the speed to suit the composition of the train, that is to say, the weight of train.

In the case of another Oerlikon mode of control (see Swiss Patent 142626), the governor of the Diesel engine acts simultaneously upon the field excitation of the main generator, through the intermediary of a small servo-motor, so that the locomotive output can be maintained, by means of the controller, at a constant value to suit the conditions of service at the time. These constant values of output, corresponding to a given running position, do not alter even in the case of variable gradients or of varying train resistances.

The controller used in this connection is built in such a way as to permit of the regulation, in an upward or downward direction, of the pressure of the main generator, by means of the servo-motor, over the whole range of regulation of the governor of the Diesel engine and on any step of the controller. Furthermore, a so-called limiting current relay serves to ensure that the servo-motor remains in operation only as long as the main generator is not overloaded as regards current loading. On the other hand, the controller has contacts which alter the speed of the Diesel engine in several steps so that, on the first steps of the controller, for instance, the engine runs at the lowest speed and on the following sets of contacts at the higher speeds. As a rule, three speeds are regarded as sufficient. The driver sets the controller for a given output of the Diesel engine to suit the conditions on the section of line or the train weight, immediately on starting the run. If the speed proves to be too small, the controller can be moved further and set for a higher speed, after which the regulation for constant output takes place automatically. The mode of control is, therefore, similar to that used on purely electric locomotives arranged

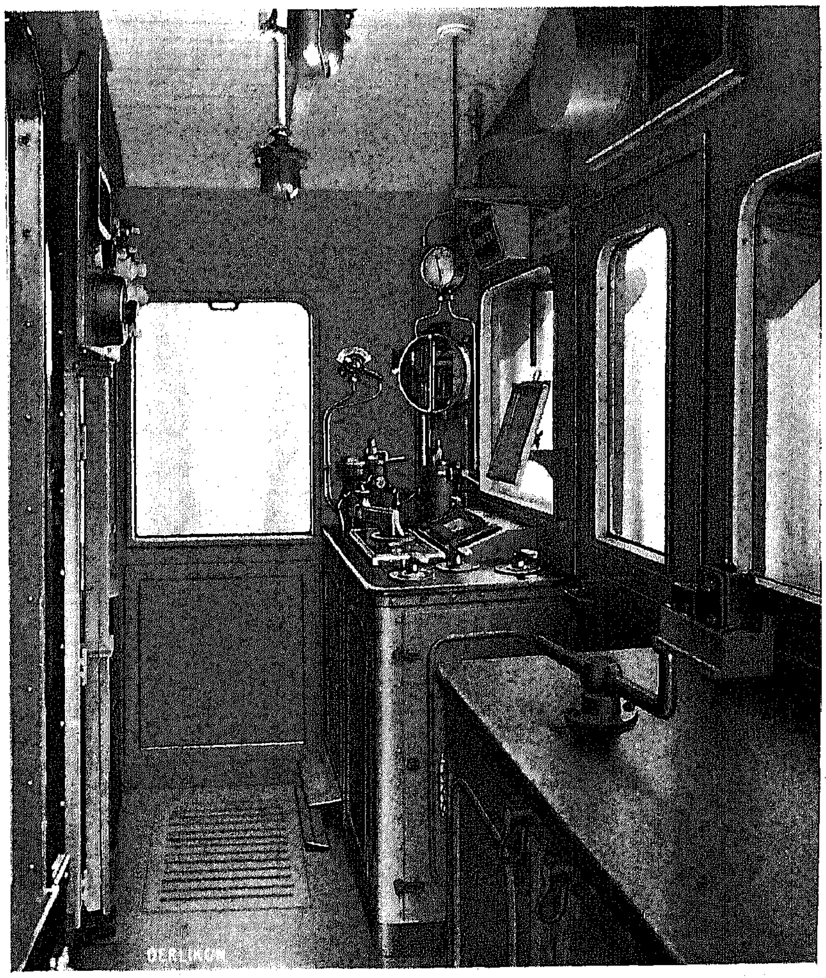
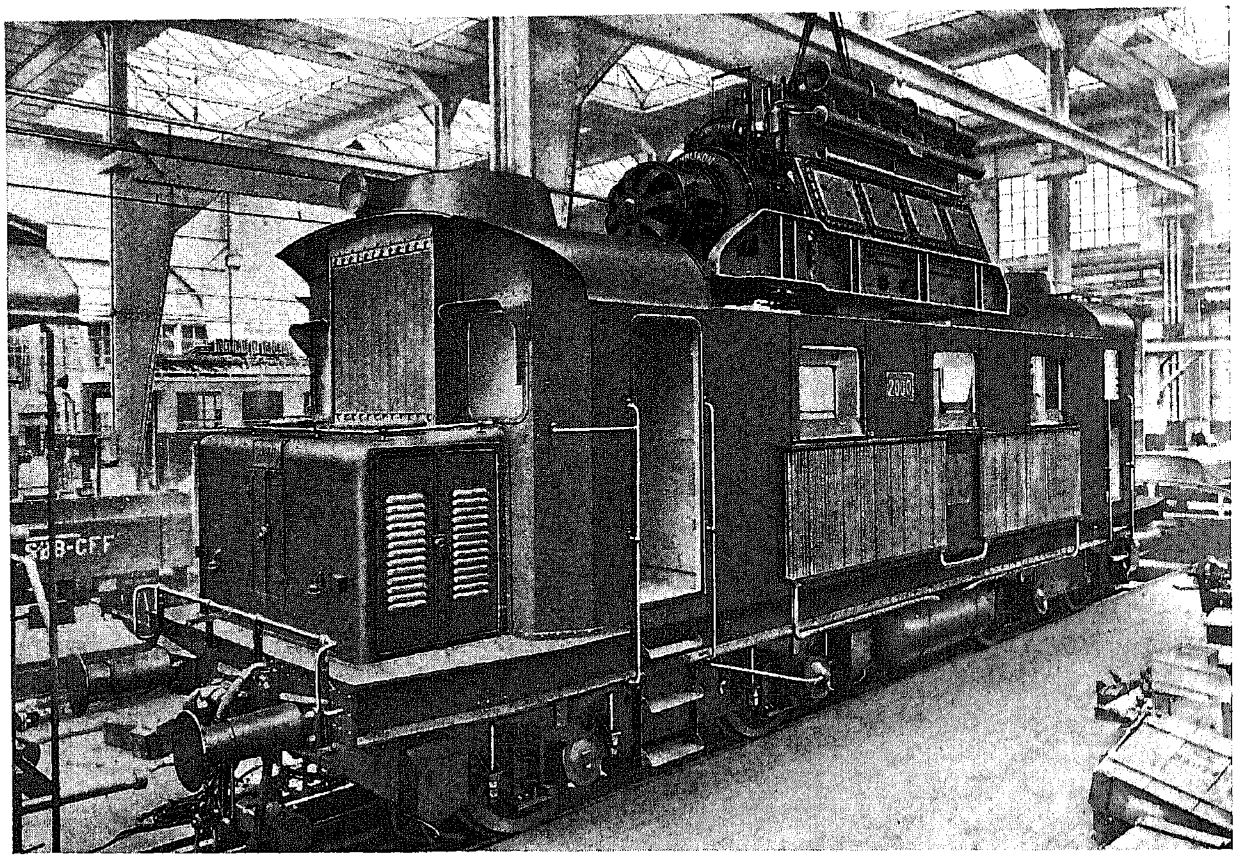


Fig. 6. Driver's cab of the 420 HP. motor coach for the Swiss Federal Railways.

for automatic switching. The controller can be brought from any one position to the other. In order to permit, for instance, of starting up under severe conditions, the controller can be set, even while the locomotive is at standstill, in the position corresponding to the highest step and the maximum output of the Diesel engine, and be left there as long as the permissible speed is not exceeded.


750 HP. Diesel-electric locomotive of the South Manchurian Railways.

An overloading of the Diesel engine is not possible with this mode of control, even in the event of the mis-firing of individual cylinders as the regulation steps are adjusted automatically according to the degree of admission. Figs. 3 and 4 show the mode of connection and give the tractive effort-speed curves for constant output, for the above method of regulation in the case of 11 controller steps, for instance, three different speeds of Diesel engine being provided for. The Diesel engine is fully utilised at these speeds, in the positions 5, 8 and 11, of the controller. The current limiting relay limits the value of the maximum permissible tractive effort. The mode of control described can also be used on locomotives for one-man operation, in combination with the so-called dead man's handle device.

(to be concluded)

Notes and News Items.

Performance of Oerlikon Locomotives. In Bulletin No. 115, we referred to the very good results obtained with the commutators of the motors on the Oerlikon single-phase locomotives. Now, we are in a position to give particulars of the highly satisfactory performance of the Oerlikon D. C. locomotives under severe conditions of service.

In accordance with the wishes of the Paris-Orleans Railway Co, 5 of the 80 freight locomotives *) ordered by them in 1922, which are being utilised, in greater part, for express and passenger service, were altered so as to permit of their use for the fastest express trains running at speeds averaging about 60 mph. The alteration in question consisted merely in fitting gears with a ratio of 1 : 2.7, in place of the gears with a ratio of 1 : 3.47, such as provided on the other locomotives; in this way, the speed could be raised from 55 mph to more than 68 mph. Springs have been incorporated in these gears with a view to protecting the gears and motor armature against the heavier impacts caused by the track, when travelling at these higher speeds. The arrangement of springs is similar to that which was adopted experimentally by the Paris-Orleans Railway Co. for the gears of locomotive EBB 101 and has given very good results during many years of service.

In spite of the heavy stresses to which all parts of these locomotives are subjected at the high speeds, the performance was always very satisfactory. This can best be seen from the high mileage dealt with by the locomotives. It may, therefore, be of interest to give a few data in this connection. In July 1930, which we have chosen owing to the heavy traffic during that month, the average mileage per locomotive was, in the case of the 158 B_0B_0 locomotives supplied to the Paris-Orleans Railway by different firms, including the Oerlikon Co., and used for main line service, 3167 miles. If, however, we take the 60 Oerlikon locomotives alone, they covered, on an average, a mileage of 4547 miles, as compared with 2329 miles in the case of the 98 locomotives of similar design supplied by other firms. The maximum monthly mileage covered, up to the present, by an Oerlikon locomotive fitted with standard gear, without springs, is 12,599 miles.

The 5 locomotives with a gear ratio of 1:2.7 covered 9831, 12,189, 12,281, 13,468 and 773 miles, respectively. The last locomotive was used during the month in question as a standby and did not take part in the train service; in view of this, the results obtained with that locomotive are not representative. The average mileage for the month was thus, in the case of the other 4 locomotives, 11,942 miles with a maximum of 13,468 miles.

These figures are very good, specially if it is borne in mind that the 5 large express locomotives in service on the Paris-Orleans Railway, which are specially built for very high speeds and high outputs, and are of three different types (2 D_0 2, 2 BB 2 and 2 C_0 C_0 2), covered during the same month of July an average mileage of about 6510 miles, the highest figure attained being 10,381 miles.

*) See Bulletins Nos. 20 and 70/71.

ATELIERS DE CONSTRUCTION OERLIKON, OERLIKON

BULLETIN OERLIKON

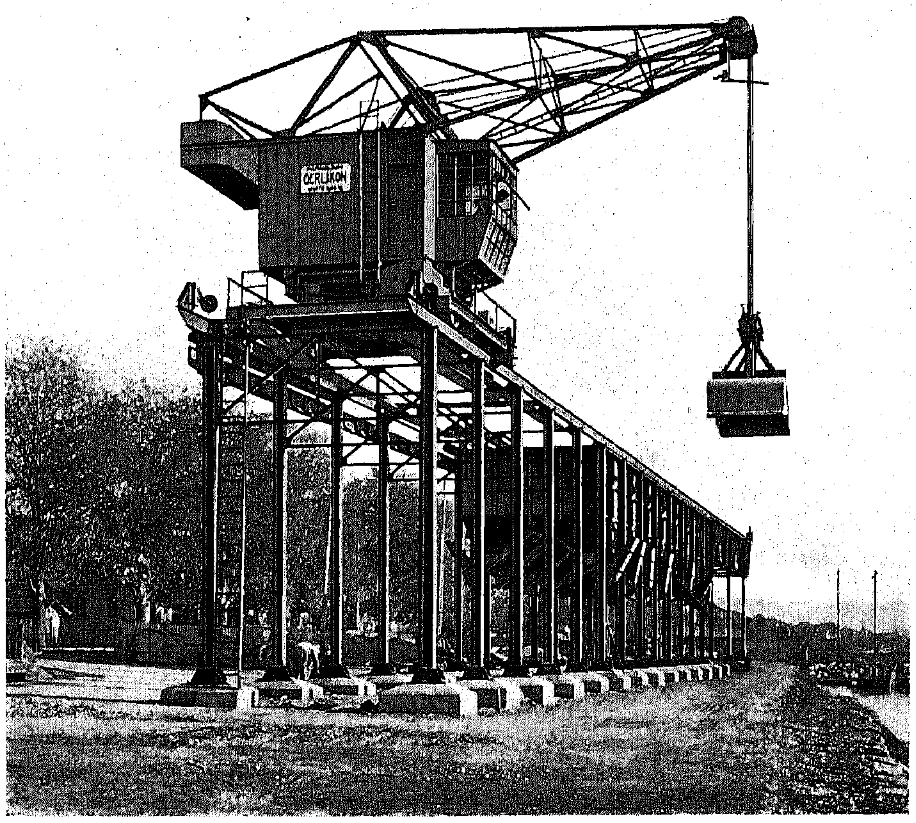
No. 117 — March 1931

Contents:

Notes:

Calculation of the Motor Output required for the Slewing Gear of Slewing Cranes with Single Roller Track.*)

The most difficult problem designers have to deal with, when determining the necessary motor output for the various motions of slewing cranes, is the calculation of the power required for the slewing motion. This applies, it is true, not so much to small jib cranes with thrust and guide bearings, but more especially to cranes where dimensions and speeds necessitate the provision of a roller track. In the case of heavy designs and with a view to economising, as far as possible, the power required, the revolving part, as well as the fixed part, are provided with a roller track. The rollers form a live ring between these two tracks and transmit the vertical pressure from the revolving part to the under-carriage without the journals of the rollers being subjected to any stresses. Slewing cranes of average dimensions are normally provided with only one roller track, which is either on the fixed or on the revolving part, the supporting rollers being arranged on the opposite part; the vertical pressure thus acts also on the journals of the rollers. This is the type of crane most used at the present. The most frequent application of this design is for harbour cranes, but it is also used in connection with loading bridges. The calculation of the motor output required for the slewing gear of such a crane forms the object of this study and we propose to examine all factors which influence it, and to determine their magnitude. After doing so, we shall consider the case of a crane actually built and compare the calculated values with the results of tests. In this connection, we shall consider an Oerlikon crane. The external appearance of the slewing crane in question can be seen from Figs. 1 and 2. The arrangement of the slewing gear is shown diagrammatically in Fig. 3. The motor, which has an output of 5 H.P. at 1450 r. p. m. drives the rollers through worm gears with a ratio of 1:12, spur gears with 8 π pitch and 16/50 teeth, with intermediate gear wheel with 48 teeth, and spur gears with 10 π pitch, and 14 and 51 teeth. One of the sets of gear wheels driving the rollers has an intermediate pinion with 14 teeth. The slewing speed of the crane is 0.033 revs./sec. The rollers have a diameter of 500 mm (1′7.6″). The mean diameter of the roller path is 2700 mm (8′ 10″); the peripheral speed of rollers is 0.28 m/sec. (11″ per sec). The rollers are cylindrical in their outer diameter. In order to be correct, from a constructional point of view, the rollers should actually be conical and the surface of the rail of the roller path inclined accordingly (see Fig. 4). When, however, the ratio between the width of rail and radius of curvature of roller path is relatively small, it is the practice to use, for the sake of economy, cylindrical rollers and flat rails. This means that, when revolving, the outer rim of the rollers has to slide on the rail and this gives rise to a somewhat greater friction work.



*) The output of the slewing motor of a slewing crane is to be determined by calculation and compared with that derived from tests. The question of using a correction factor to be applied to the results of calculations will be examined.

When calculating the motor output of the slewing motor during normal operation, we have to consider the friction work under the following heads:—

1) Work due to the sliding friction of the rollers on the rail.
2) Work due to the friction of the journals.
3) Work due to the friction of the hub of the rollers.
4) Work due to the friction of the central column.
5) Work due to the rolling friction.
6) Work due to the friction in the winding gear.
7) In certain cases, the effect of the wind has also to be taken into account.

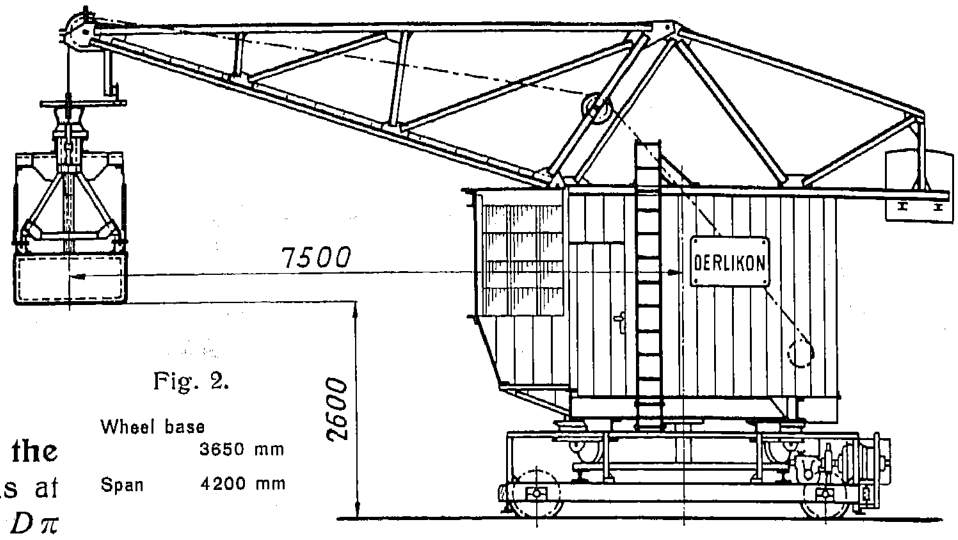


Fig. 2.

Wheel base 3650 mm

Span 4200 mm

1) **Work due to the sliding of the rollers on the rail.** When the crane describes one revolution, there is at both the points 1 and 2 (see Fig. 5) a sliding path $D\pi - \left(D - \frac{i}{2}\right)\pi = \frac{i}{2}\pi$ long. The pressure at either point amounts to half the wheel pressure so that, for a revolution of the crane, the total work due to the sliding of rollers on the rail is equal to the half sum of the wheel pressures $\left(\frac{Q}{2}\right) \times 2$ half widths of rail $\times \left(\frac{i}{2}\right) \times \pi \times$ friction coefficient (μ_1), or $\frac{Q i \pi \mu_1}{2}$. If the slewing crane revolves with a speed of n_1 revs/sec, the work per second amounts to

$$N_1 = \frac{Q\, i\, \pi\, \mu_1\, n_1}{2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

2) **Work due to the friction of the journals.** The holding torque due to the sliding friction of rollers on the rail $P_1 \times \frac{1}{2} = \frac{Q \mu_1 i}{2}$ increases the friction work of the journals. The total friction work of journals is made up of the friction work due to the wheel pressure and of that caused by the above mentioned holding torque. If we designate the friction coefficient by μ_2, the total friction resistance Wa of the journals, referred to the diameter of the rollers, is $Wa = (2\,P_1 + Q)\,\mu_2 \frac{d_1}{d_3}$; the formula for the holding torque gives us $P_1 = \frac{Q \mu_1 i}{l}$, hence

$$Wa = \left(\frac{2\,Q\,\mu_1\,i}{l} + Q\right)\mu_2 \frac{d_1}{d_3} = Q\left(\frac{2\mu_1\,i}{l} + 1\right)\mu_2 \frac{d_1}{d_3}$$

If the peripheral speed of the rollers is v m/sec, the friction work of the journals per second is

$$N_2 = Q\left(\frac{2\mu_1\,i}{l} + 1\right)\mu_2 \frac{d_1}{d_3}\,v \quad . \quad . \quad . \quad (2)$$

3) **Work due to the friction of the hub of the rollers.** The lateral friction pressure acting on the hub of the rollers cannot reach a higher value than the product of the wheel pressure by the friction coefficient between roller and rail. We have already designated this friction coefficient by μ_1. We shall denote the friction coefficient for lateral hub friction by μ_3. The friction resistance Wn of the hub, referred to the diameter of the rollers, is:

$$Wn = \frac{Q\,\mu_1\,\mu_3 \left(\dfrac{\frac{d_2}{2} + \frac{d_1}{2}}{2}\right)}{\dfrac{d_3}{2}} = \frac{2\,Q\,\mu_1\,\mu_3\left(\frac{d_2}{4} + \frac{d_1}{4}\right)}{d_3}$$

Hence, the friction work of the hub per second is:

$$N_3 = \frac{2\,Q\,\mu_1\,\mu_3\left(\frac{d_2}{4} + \frac{d_1}{4}\right)}{d_3}\,v \quad . \quad . \quad (3)$$

4) **Work due to the friction of the central column.** The bearing pressure in the case of the central column is equal to the resultant of the friction pressures acting on the hub. We have seen that the latter are a direct function of the roller pressure and as, when the crane is fully loaded, the front rollers have to carry nearly the whole load and are relatively close together, we can assume a value of about $0.8\,Q\,\mu_1$. If d_4 is the diameter of the central column and μ_4 the friction coefficient in the bearing, the corresponding friction resistance We, referred to the roller path or to the periphery of the rollers is:

$$We = \frac{0.8\,Q\,\mu_1\,\mu_4\,\frac{d_4}{2}}{\frac{D}{2}} = \frac{0.8\,Q\,\mu_1\,\mu_4\,d_4}{D}$$

The friction work per second of the central column is thus

$$N_4 = \frac{0.8\,Q\,\mu_1\,\mu_4\,d_4}{D}\,v \quad . \quad . \quad . \quad . \quad (4)$$

5) **Work due to the rolling friction.** Technical text books give us as friction coefficient of the rolling motion, for the determination of the rolling friction, a value $f = 0.05$ cm, in the case of steel or hard cast-iron rollers on steel rails. The total resistance Wr of the rolling friction, referred to the diameter of the rollers, is thus

$$Wr = \frac{0.05\,Q}{\frac{d_3}{2}} = \frac{0.1\,Q}{d_3}$$

and the work per second: $\quad N_5 = \frac{0.1\,Q}{d_3 \text{ in cm.}}\,v \quad . \quad . \quad . \quad (5)$

6) **Friction work in the winding gear.** It is necessary, when calculating the motor output, to determine, in addition to the resistances of the carrying rollers, those encountered in the reduction gear between the rollers and the motor. This gear comprises spur gear and worm gear with the corresponding shafts and bearings.

The calculation of the friction losses in these parts would lead us too far. It is, in fact, not necessary to do so, as there are sufficient data available in the technical literature to enable us to determine these losses as a percentage of the load. The total efficiency is made up of the efficiencies

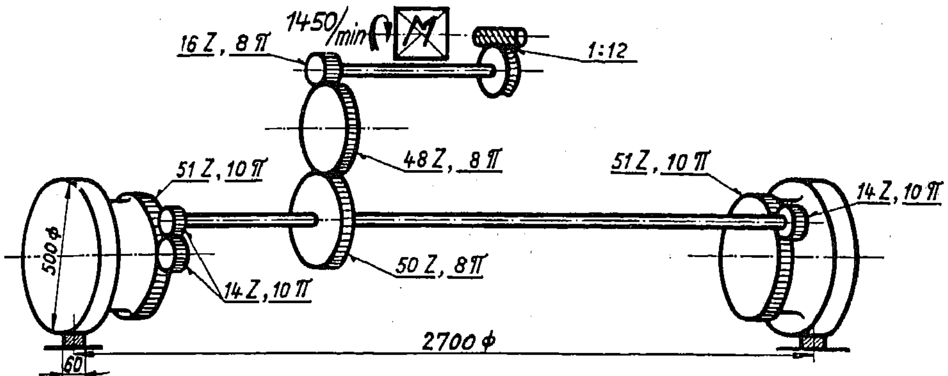


Fig. 3.

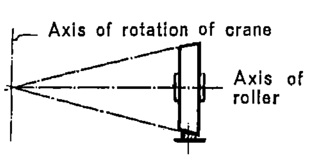


Fig. 4.

G = Sum of the 4 wheel pressures

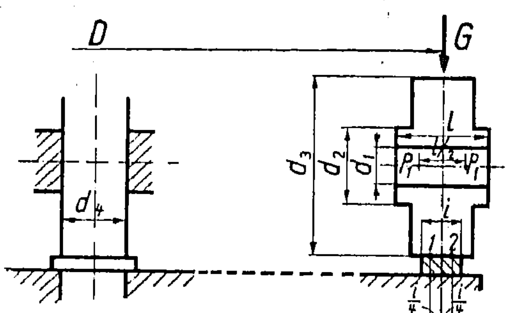


Fig. 5.

of the individual sets of gears, such as provided for in the case of the reduction gear in question.

7) **Resistance of the wind.** When determining the output of the motor for the slewing gear of the crane, it is necessary to take into account, apart from the friction losses, the effect of the wind in cases where the crane is exposed to the wind. In this connection, the designer aims, in very first place, at obtaining, as far as this is practicable, a shape of crane which renders the resulting wind torque, applied to the axis of rotation, as small as possible. If there is such a torque, it is necessary to examine whether the motor is capable, with its maximum output, to start up against the force of the wind. The total work to be developed by the motor, insofar as the wind effect is concerned, is theoretically zero, as the resultant force of the wind helps or opposes the motor, according to the direction of rotation of the latter. The size of the motor is thus only affected by starting conditions against the wind.

We can now turn to the actual calculation of the motor output. For this purpose, we shall first set out the figures given in the technical literature for the friction coefficients; these are as follows:—

μ_1 for steel/steel, according to Galton and for $\frac{16.7 \times 60}{1000} = 1$ km/hour: about 0.22

μ_2 for steel/bronze: 0.08

$\mu_3 = \mu_2$

$\mu_4 = 0.1$

The work due to the sliding friction of the rollers calculated by means of formula 1) with $Q = 19600$ kgs, $i = 0.06$ amps and $n_1 = 0.033$ rev/sec, is:

$$N_1 = \frac{19600 \times 0.06\,\pi \times 0.22 \times 0.033}{2} = 13.5 \text{ kgm/sec.}$$

The work due to the friction of the journals derived from formula 2) with $l = 0.18$ m, $d_1 = 0.7$ m, $d_3 = 0.5$ m, and $v = 0.28$ m/sec, is:

$$N_2 = 19600\left(\frac{2 \times 0.22 \times 0.06}{0.18} + 1\right) 0.08 \frac{0.07}{0.5} 0.28 = 70.5 \text{ kgm/sec.}$$

The work due to the friction of the hub of the rollers determined by means of formula 3) with $d_2 = 0.13$ m, is:

$$N_3 = \frac{2 \times 19600 \times 0.22 \times 0.08 \left(\frac{0.13}{4} + \frac{0.07}{4}\right)}{0.5} 0.28 = 20 \text{ kgm/sec.}$$

The work due to the friction of the central column derived from formula 4) with $d_4 = 0.16$ and $D = 2.7$ m, is:

$$N_4 = \frac{0.8 \times 19600 \times 0.22 \times 0.1 \times 0.16}{2.7} 0.28 = 5.7 \text{ kgm/sec.}$$

The work due to the rolling friction calculated by means of formula 5) is: $N_5 = \frac{0.1 \times 19600}{50 \text{ (cm)}} 0.28 = 11$ kgm/sec.

We still have to take into account the **friction work in the winding gear** and, for this purpose, we group together the efficiencies of the individual parts of the reduction gear. The efficiency per pair of gear wheels engaging each other is, in the case of cranes, about 96 %, and that per bearings of one shaft about 97 %. The Oerlikon worm gear, size S 3, with a ratio of 1:12, has, with the load in question, an efficiency of 88.2 %. The total efficiency thus amounts to $0.96^3 \times 0.97^3 \times 0.882 = 0.71$.

The total output required in H. P. is obtained as follows: $\frac{13.5+70.5+20+5.7+11}{0.71 \times 75} = 2.27$ HP.

The current consumption of the motor for a load of 4650 kgs, measured in various positions of the slewing gear is, when the air is still, as follows:

Minimum value: 5.5 amps with direct current at 550 volts.
Maximum value: 7.5 amps with direct current at 552 volts.

The efficiency of the motor is, in the first case, 0.76 and in the second case 0.77, so that the actual motor output required is:

Minimum value: $\frac{5.5 \times 550 \times 0.76}{735} = 3.15$ H. P.

Maximum value: $\frac{7.5 \times 552 \times 0.77}{735} = 4.35$ H. P.

In the case of a load of 4650 kgs, Q is 650 kgs larger than the value introduced in the calculations. We have, therefore, to apply, as correction factor to the measured values, the coefficient $\frac{19600}{19600+650}$. In this way, we obtain as minimum value 3.05 H. P. and as maximum value 4.25 H. P. and as mean value 3.55 H. P. The motor output arrived at theoretically is, therefore, too small, and has, in this case, to be increased by at least 60 %. As the friction coefficients used, are figures obtained from experience, the discrepancy cannot be due to faulty calculations. There must be, therefore, a further resistance to be overcome, which however cannot be easily obtained by calculation. The resistance in question must be one due to the sagging of the rail supports under the pressure of the rollers. This sagging is made up of the sagging of the intermediate supports and of the sagging of the whole frame. The understructure of the rails has, at some places, more rigid points and at others more flexible points, which explains the fact that the current consumption of the motor, measured at different points, varies so much.

It is, therefore, necessary, in cases where the understructure of the rails is not entirely rigid, to apply a coefficient to the result of calculations. The value of this coefficient is governed by the value of the stresses and the design of the under-structure of the rails; it is advisable to make somewhat ample allowance in this connection.

Cable Drums with Sliprings for Electric Cables.

Cable drums with sliprings serve for winding and unwinding electric cables for the power supply of electric motors. The end of the cable in the interior of the drum is led to insulated brushes, which rest on sliprings provided on the fixed spindle of drum. The spindle of the drum is often made hollow, so that the cable connecting the sliprings to the supply can be drawn through it.

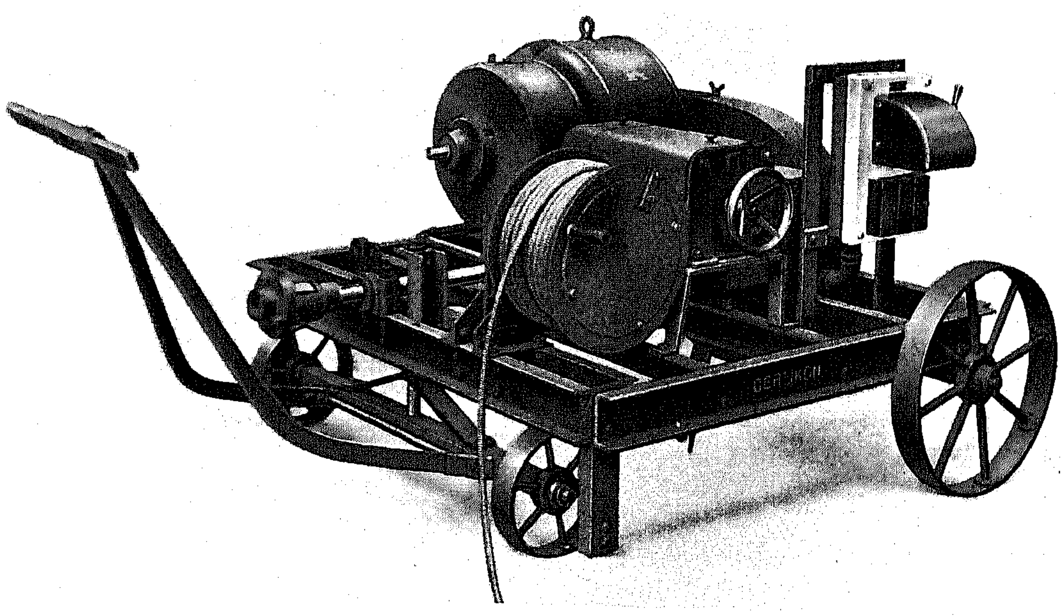


Fig. 1. Cable drum of a portable electric drive for winding and unwinding by hand.

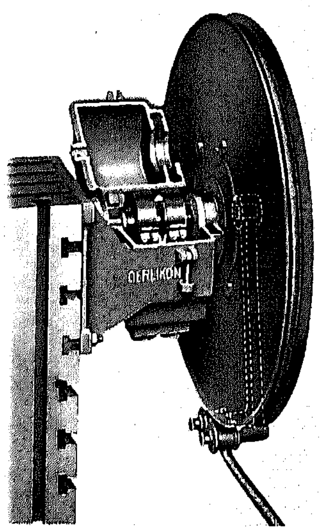


Fig. 2. Cable drum for the automatic winding and unwinding of cable. Slipring casing open. (The movable guide arm for the cable is indicated in dotted line in white).

The applications of cable drums are varied and their design depends upon the type of plant they are meant for; they are found on portable electric driving equipments and are further used for the power supply of movable cranes or on the cranes themselves, for transmitting the current from the crane to the electric appliance suspended to the hook. Cable drums of large dimensions, in the case of which gearing has to be provided for the winding and unwinding of cable, are utilised, in connection with the sinking of shafts, for the power supply of pump motors.

The cable on the drums of portable driving equipments is usually wound and unwound by hand. Fig. 1 shows, for instance, a drum of this type. This design is, however, seldom used for the power supply cables of movable cranes. It can, of course, only be resorted to in cases where the driver follows the crane on foot. If the driver is seated in a cab on the crane itself, the drum must wind and unwind the cable automatically. The type of cable drum suited for the purpose is shown in Fig. 2. The cable is wound on the drum in a vertical plane. Flat cable is that most indicated for such a design of drum, but round cable can also be used. There is no possibility of entangling or faulty winding of cable, an occurrence which is inevitable with the design of drum shown in Fig. 2. As far as operation is concerned, it is immaterial whether the cable drum is stationary or whether it is fitted on the crane to which the current is to be led. The cable is unwound by drawing it out.

When the drum is revolved in the direction corresponding to the unwinding of cable, energy is stored by any kind of appliance and this energy is used for rewinding the cable. There are two arrangements which serve this purpose. One consists in storing the energy for winding in a spiral spring. Such a design is shown in Fig. 3. It is, however, from an economical point of view, only suitable for small lengths of cable. In the case of the other designs, the spiral spring is replaced by a rope drum on which is wound a thin rope supporting a weight suspended in the manner of a pulley block. At the same time as the cable is unwound, the weight is raised and the energy thus stored used for rewinding

the cable. Such an arrangement is shown in Fig. 4. The weight is enclosed in the sheet metal case which can be seen on the right. This automatic rewinding arrangement is simple and reliable; it has given good results in practice.

The third application of cable drums, to which reference has been made, i. e. where the cable drum is used for transmitting the current from the crane to the gear suspended to the hook, necessitates the use of a cable drum with automatic rewinding device. A typical instance of the kind is the case of cranes with lifting magnets (Figs. 6 and 7). Cable drums with automatic rewinding device, such as previously described can, of course, also be used here, provided there is sufficient room for the latter. It is, however, often not possible, owing to the limited height available, to adopt the rewinding arrangement with counter-weight. On the other hand, the relatively large diameter of drum,

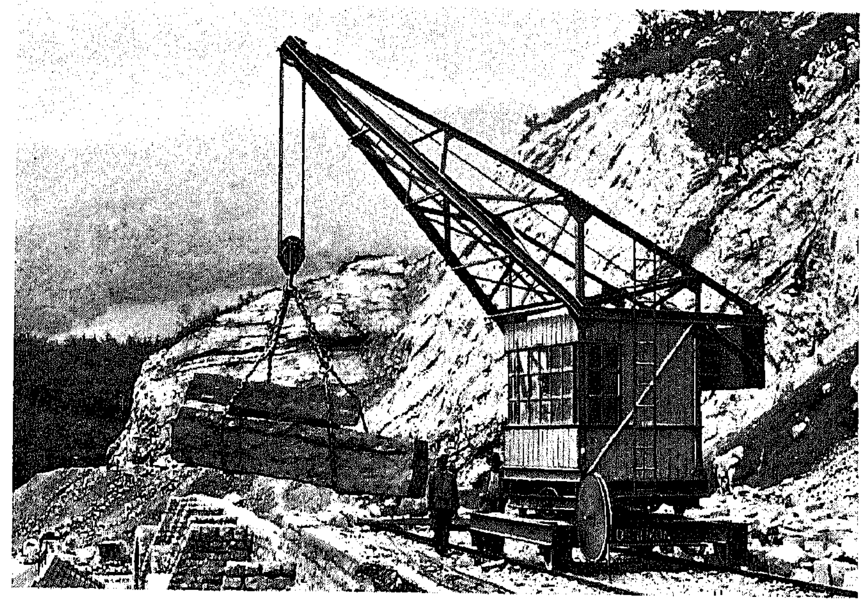


Fig. 3. 5-ton slewing crane with cable drum for automatic rewinding of cable by means of spring.

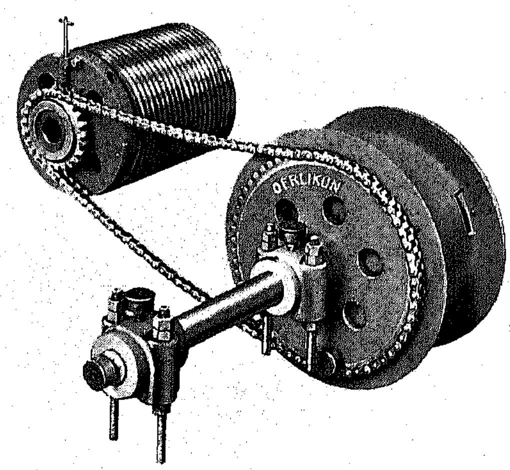


Fig. 5. Cable drum operated off the hoisting gear. The sliprings, which are arranged in the drum, are easily accessible.

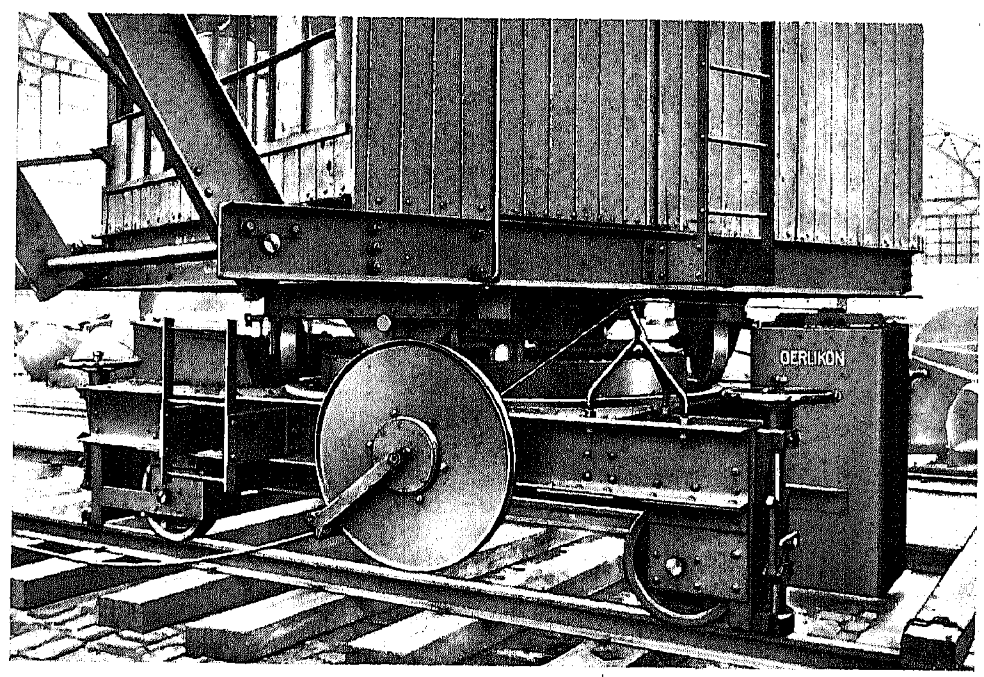


Fig. 4. Cable drum with automatic rewinding on undercarriage of a slewing crane.

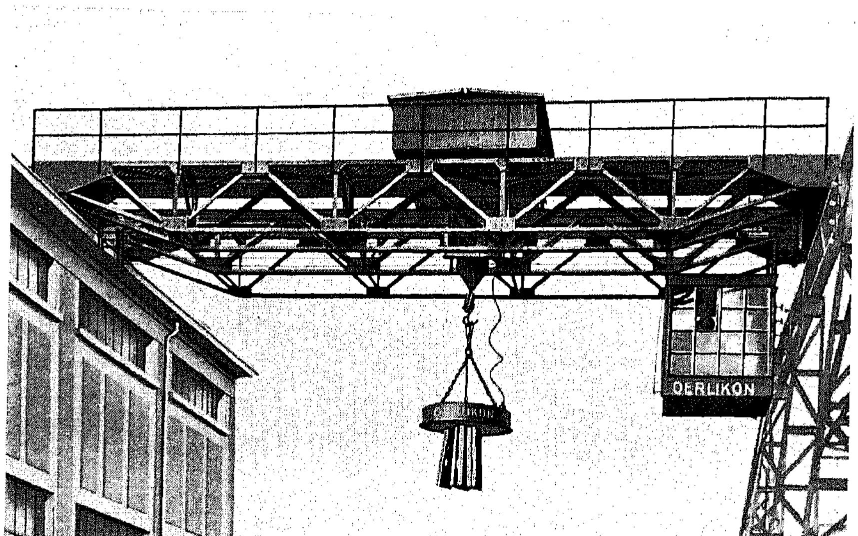


Fig. 6. Travelling crane with lifting magnet for a foundry yard.

in the case of the design with rewinding spring, shown in Fig. 2 often makes it impossible to accommodate the drum on the crane. For this reason, the Oerlikon Company adopt, in such cases, the design represented in Fig. 5, where the cable drum is permanently coupled to the hoisting gear or to the main drum. The diameter of the cable drum is fixed by the thickness of the electric cable. It is, therefore, necessary to allow for a suitable transmission ratio between hoisting gear and cable drum, so as to adapt the unwinding of cable to the path of the hook carrying the load. As, however, there is a possibility of the cable not winding perfectly uniformly, the sprocket wheel on the cable drum side is connected to the latter in the manner of a friction coupling. The sprocket wheel on the main drum can be uncoupled in order to be able, in certain cases, to put the cable drum out of service, when the hook of the crane is used for long periods, without the lifting magnet.

As last application of cable drums, mention can be made of the design shown in Fig. 8. This type of drum is used when the cable has large dimensions. The torque required for winding the cable is so large that multiple gears have to be utilised for the purpose. Such a drum comes rather under the category of a cable winch than of an ordinary cable drum. The design represented in Fig. 8 is one adopted by the Oerlikon Company for the power supply cable of a sinking pump motor with an output of 800 HP. running off a three-phase, 3000 volts, 50 cycle supply. The cable has an outer diameter of 40 mm (1.57 in.) and weighs 6 Kgs. per m. (4 lbs. per ft.). The length of cable is 300 m. (980 ft). The cable is wound in four layers. The drum can be worked either by hand or by electric motor. The motor is arranged for belt drive.

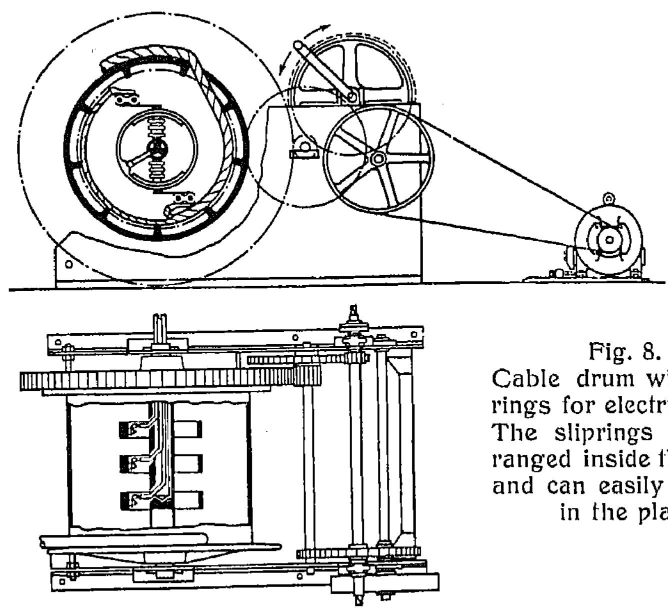


Fig. 8.
Cable drum with sliprings for electric cable. The sliprings are arranged inside the drum and can easily be seen in the plan.

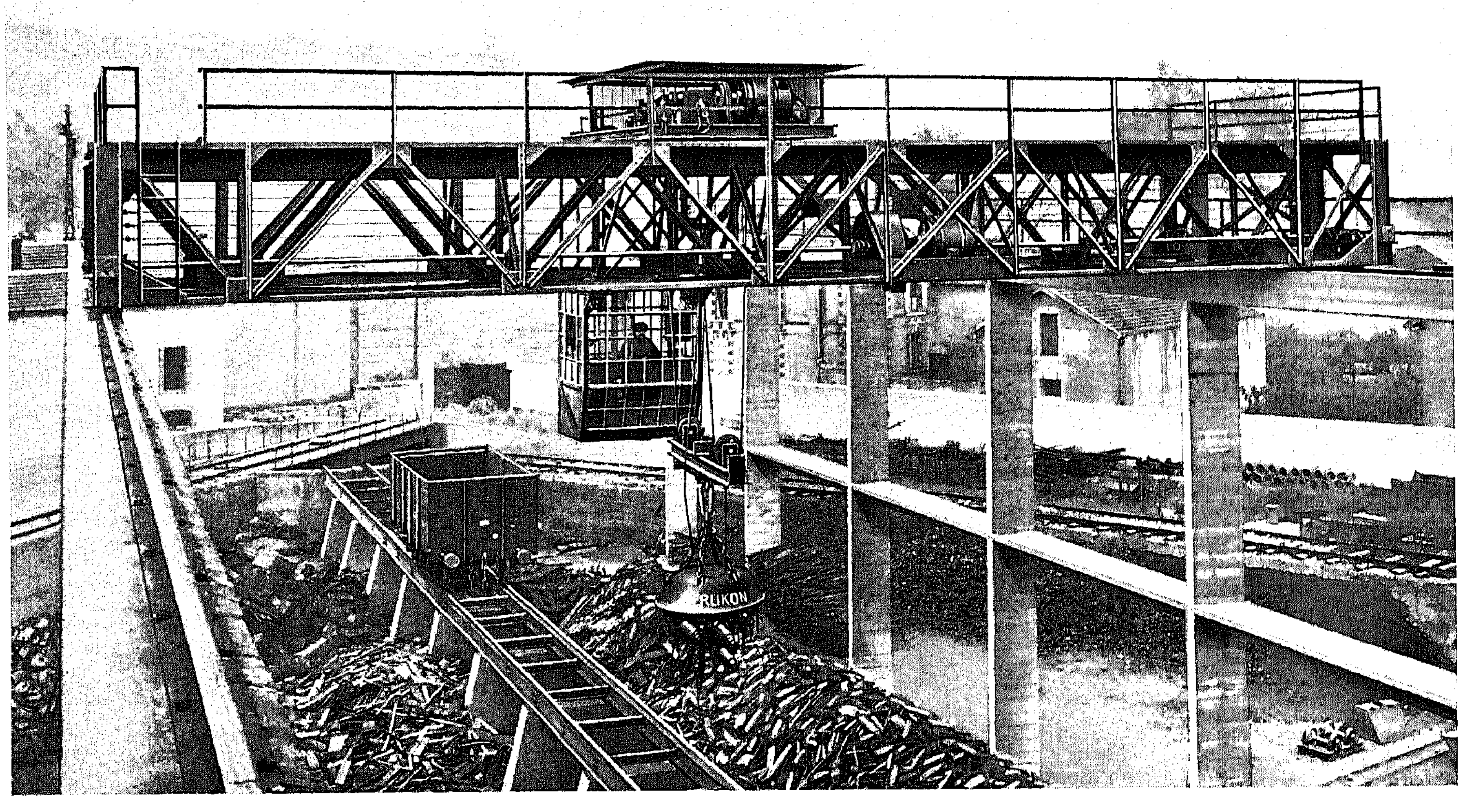


Fig. 7. Travelling crane with lifting magnet for the scrap iron storage yard of steel works.

NOTES AND NEWS ITEMS.

Travelling Charging Cranes for Handling Packets of Laminations. One of the special types of cranes used in steelworks, which plays a very important part in such installations, is the charging crane. The function of this crane is either to charge melting furnaces with raw material or to insert into reheating furnaces ingots or packets of laminations. The design of the crane is governed by the function it has to perform, i. e. getting hold of troughs filled with raw material, or of ingots or packets of laminations, lifting of the latter, transport up to the door of the furnaces, introduction and emptying or depositing of the materials, and, furthermore, in the case of reheating furnaces, removal of the materials too.

The travelling charging cranes are built in their general lines as follows:— The crane itself is a standard crane equipped with a crab under which is arranged a rigid frame; the latter carries at its lower extremity, at the same level as the door of the furnace, the charging gear with driver's platform, this gear being suspended in such a way that it can revolve in a horizontal place. In order to permit of the lifting of the troughs or ingots or packets of laminations,

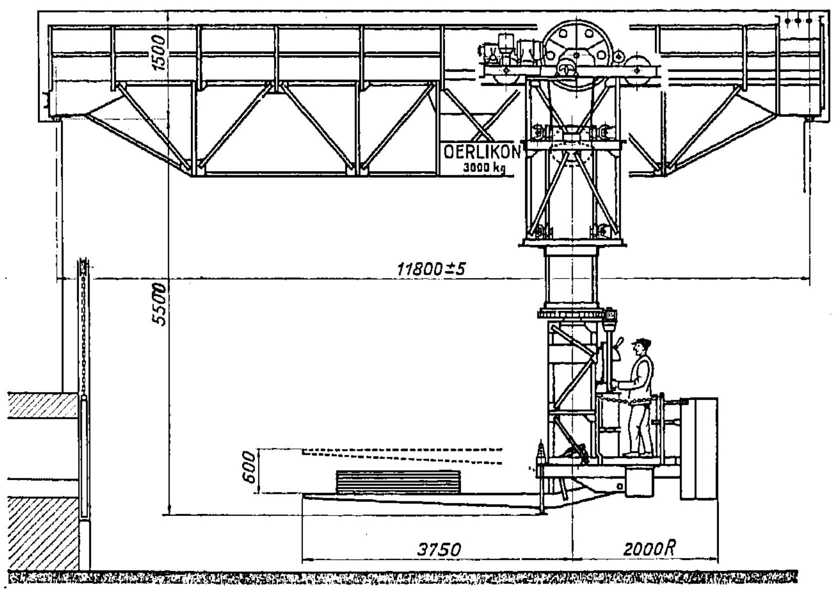
provision is made on the crab for hoisting gear for lifting and lowering the whole revolving part.

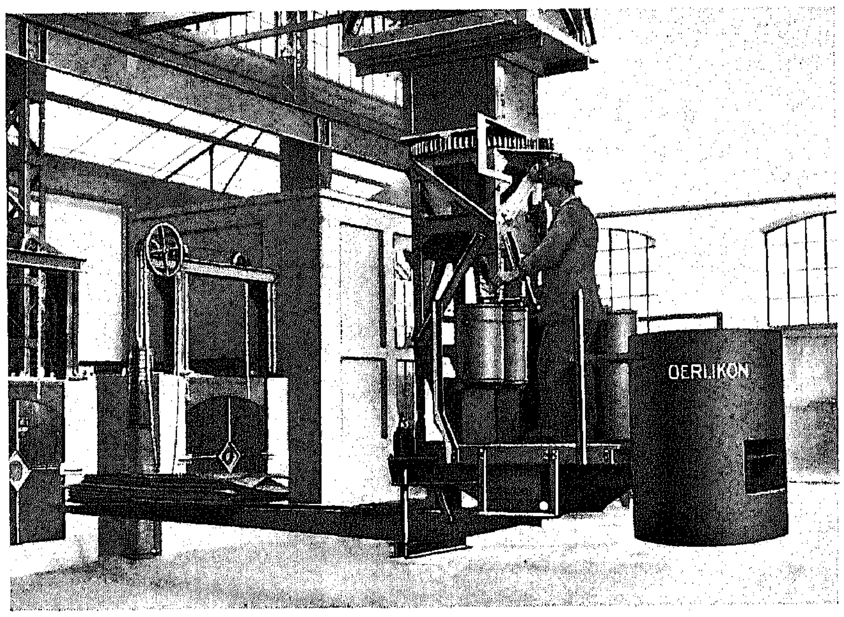
The charging bar with which the troughs are held, or the supporting arms on which the ingots, or the packets of laminations rest, are supported in a flexible manner in order to prevent excessive stresses in the event of their coming to rest against the floor. The charging bar is further so arranged that it can be revolved about its axis when tipping the troughs.

The Oerlikon Company have recently supplied to the Società Metallurgica Italiana, Milan, two travelling charging cranes. These cranes are for introducing into pre-heating furnaces, specially built for the purpose, packets of laminations up to 6600 lbs. in weight, where they are heated up to the necessary temperature for further treatment. Provision is made in the floor of the furnaces for two channels, into which the two supporting arms of rectangular section of the charging gear are lowered, when depositing the laminations.

We propose to give below a few particulars regarding the design of these two charging cranes; the main dimensions of the plant are indicated in the illustration below. The travelling crane which runs on four rollers, two being driving rollers, and the crab are of standard construction. The crab supports a rigid rectangular guide frame, in which the hoisting frame moves up and down; the latter is also rectangular and is guided by 16 rollers (four on each side). The hoisting frame itself supports a centre shaft of substantial design so arranged that it can revolve. This centre shaft is rigidly fixed at its lower end to the revolving part while, at its upper end, it is carried by a ball bearing arranged in a cross support; the latter forms, together with the two rope pulleys it carries, the running block of the hoisting gear, and thus imparts to the revolving carriage, the hoisting and lowering motion. The vertical frame of lattice construction of the revolving carriage, suspended to the centre shaft, supports, on one side, the driver's platform and the counter-weight arranged behind it, while, on the other side it carries two supporting arms of very substantial design hinged to it. In order to prevent excessive stresses in the vertical shaft, in the event of the arms coming to rest against the floor when lowering the load, the arms are supported in such a manner as to ensure flexibility in a vertical direction. On the other hand, a limit switch stops the lowering motion of the hoisting gear when the arms exceed a certain inclination in a vertical direction. The supporting arms rest against two powerful buffer springs which damp the effect of too abrupt starting up. The driver's platform accommodates, in addition to the four controllers for the travelling, traversing. hoisting and slewing motions with the corresponding resistances, the complete slewing gear. The slewing motion is obtained by means of a pinion, engaging the toothed rim on the hoisting frame and driven by the slewing motor through worm gear and bevel gear. This pinion revolves about the periphery of the toothed rim, drawing the whole revolving carriage round with it. The slewing motion can be stopped more or less rapidly, as required, by means of a foot brake. A fuse panel with hand operated circuit breaker for the whole installation completes the equipment of the driver's platform.

The electric equipment which is for three-phase current at 250 volts, 50 cycles, is standard in the case of all four motions. Provision is made for limit switches for either direction in the case of the travelling, traversing and hoisting motions. A further limit switch prevents, as previously mentioned, a too great inclination of arms in an upward direction. Reference may also be made to the arrangement adopted for leading the current from the rigid guide frame of the crab to the hoisting frame moving up and down. As the lift amounts only to about 1′8″, actual leads and roller contacts, such as utilised for the travelling and traversing motions, have been dispensed with and use has merely been made of articulated bar connections, spring pressure being applied at the hinges in order to ensure good contact. The current is led from the hoisting frame to the rotating part, in the usual way, by means of sliprings, and the cables for the supply are drawn through the hollow central shaft.





Main dimensions of the travelling charging crane of the Società Metallurgica Italiana, Milan. On the right, revolving carriage with drivers' platform and supporting arms, in front of the door of the furnace.

The main particulars of the crane are as follows:—

Lifting capacity (useful load)	3000 kgs (6600 lbs)			
Lift	0.5 m (1′8″)			
Travelling speed	40 m/min.	(131 ft./min.);	motor output	6.3 H.P.
Hoisting speed	3.4 „	11 „	„ „	12 H.P.
Traversing speed	22 „	72 „	„ „	2 H.P.
Slewing speed	2 RPM.		„ „	2.4 H.P.

Travelling Cranes supplied to the Maag Gear Co., Zurich, and to the Erste Brünner Machine Works, Brünn. The Oerlikon Company have recently supplied travelling cranes for two interesting installations, which deserve special mention. This plant is for new workshops built on the most modern lines, the installations in question being specially notable in view of the large number of cranes provided for. The cranes of the Maag Gear Co., Zurich, which are for the new workshops this Company erected, in the Summer of 1929, for the manufacture of their well-known gear cutting machines, comprise, for the time being, four electrically operated travelling cranes. These cranes are for a 220 volts, 50 cycles, three-phase supply; they are controlled from the driver's cab and have each a lifting capacity of 10 tons at hook and a span of 41′9″ (Fig. 1). The speeds when dealing with a 10-ton load are as follows:— Travelling speed 262 ft/min., hoisting speed 32 ft/min., traversing speed 65 ft/min. The cranes are of usual design with brakes for the hoisting and traversing gear and corresponding limit switches. A notable feature about this installation is the excellent lighting of the workshops, which is further enhanced by the original light-coloured painting inside the building.

The Erste Brünner Machine Works in Brünn (Czecho-Slovakia), who have had Oerlikon cranes in operation at their Works for many years, placed again an order, also in the Summer of 1929, with the Oerlikon Company for the supply of all the cranes required for their new workshop buildings at the Luz Works in Brünn. These new workshops comprise a building with two large erection sheds and seven further sheds for workshops. The average length of the sheds is 426 ft. and the total floor surface exceeds 174,000 sq. ft. The cranes supplied comprise 18 electric travelling cranes with different lifting capacities

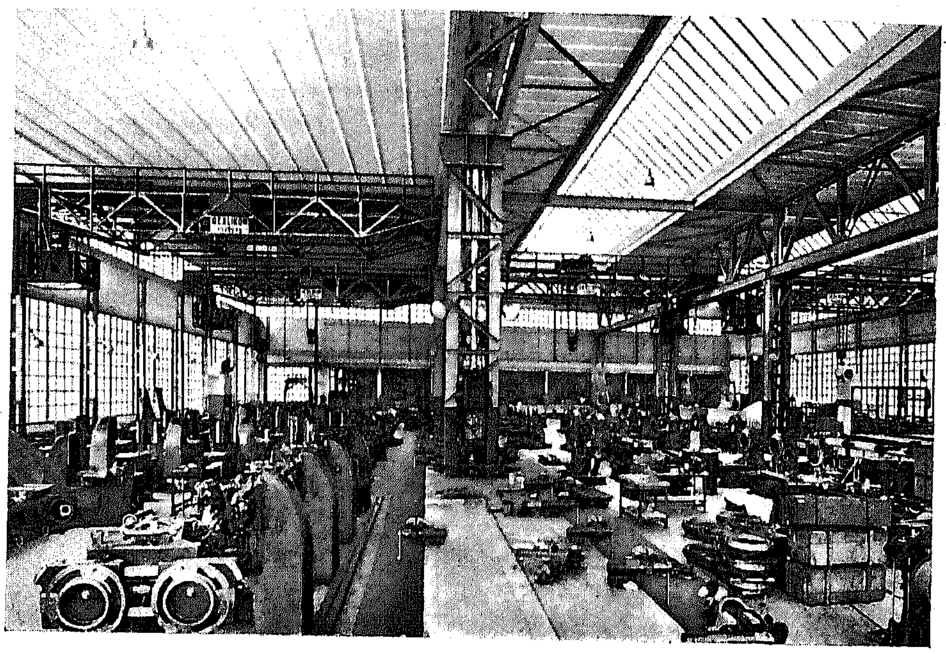


Fig. 1.

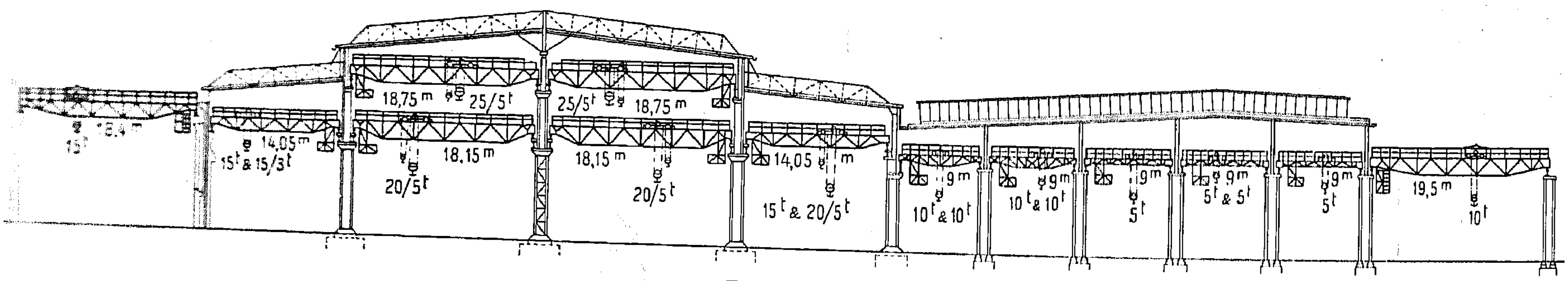


Fig. 2.

and spans (see Fig. 2) operated with three-phase current at 500 volts, 50 cycles. The following cranes are installed in the building itself: Two 25-ton travelling cranes with a span of 61′6″. Three 20-ton travelling cranes with spans of 59′6″ and 46′1″. Three 15-ton travelling cranes with a span of 46′1″. Four 10-ton travelling cranes with a span of 29′6″. Four 5-ton travelling cranes with a span of 29′6″. There are two further cranes for serving the yards, one with a lifting capacity of 15 tons and a span of 60′5″ and the other with a lifting capacity of 10 tons and a span of 64′. The 20 and 25-ton cranes have auxiliary hoisting gear for 5 tons, and two of the 15-ton cranes, auxiliary hoisting gear for 3 tons. The total lifting capacity of all 18 cranes is 240 tons. The two cranes for 25/5 tons and 20/5 tons, in the large erection sheds (see Fig. 3) travel on runways arranged one above the other. All the cranes were supplied and ready for service within the remarkably short space of time of seven months from date of order.

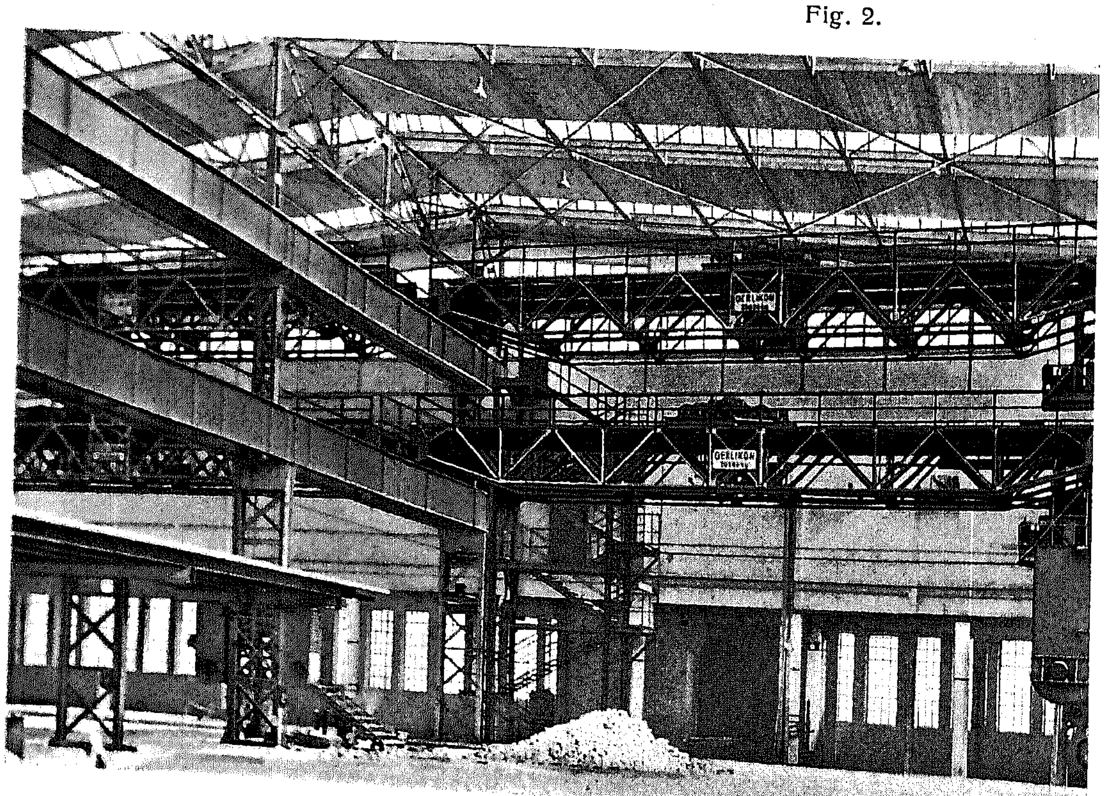


Fig. 3.

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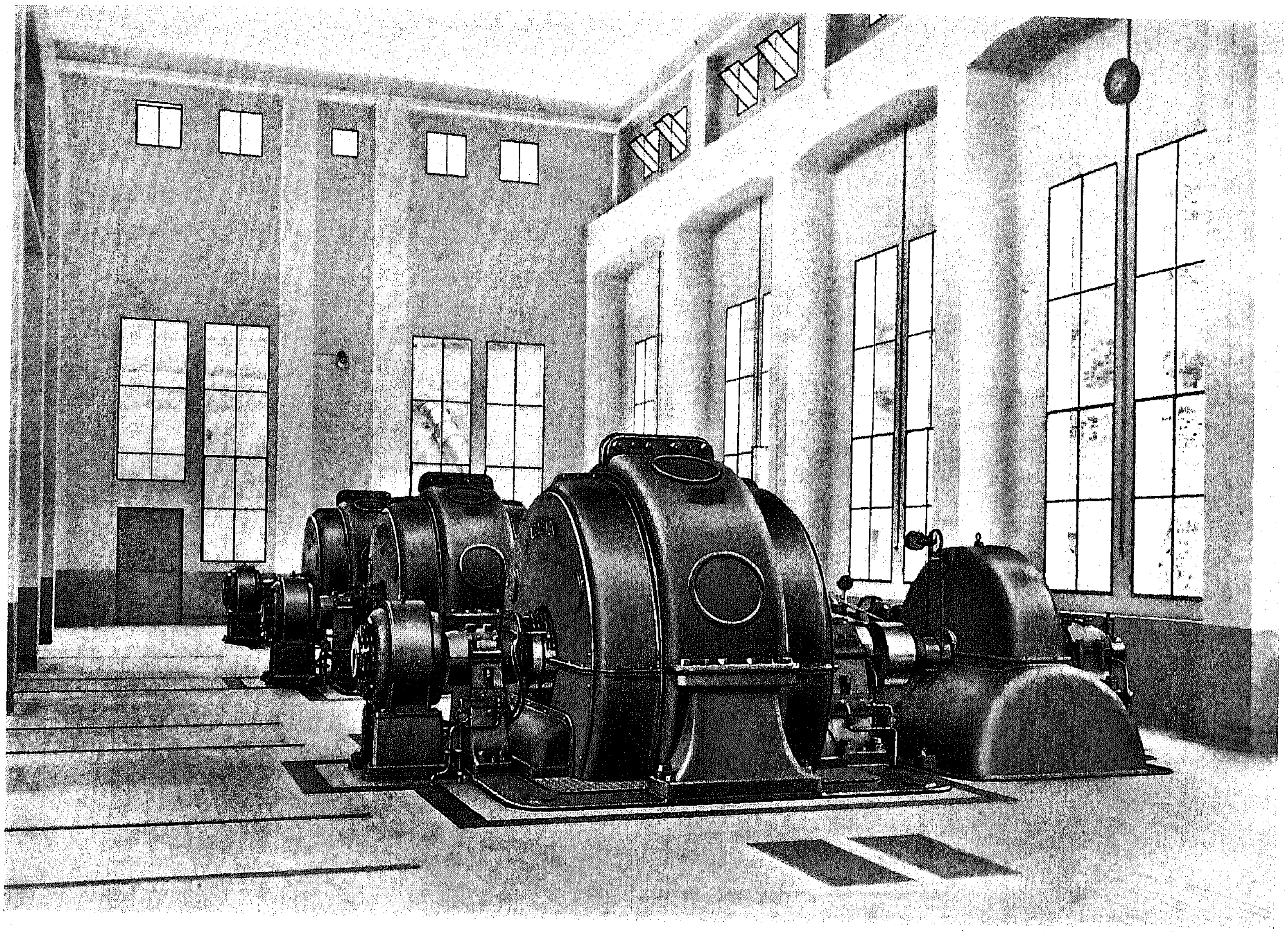


Fig. 1. Machine room of the Champsec Generating Station. Four sets of 4500 KVA each.

The Champsec Generating Station.

The Champsec Hydro-electric Generating Station of the Power Supply Company of Western Switzerland (E. O. S.) is situated in the Canton of Valais; it utilises the head of about 1800 ft. between the village of Fionnay and Champsec. The pressure pipe line, which is 4100 ft. long, was supplied by Messrs. Sulzer Bros. of Winterthur, and erected by them; it consists of electrically welded pipes and is dimensioned for a quantity of water of 88 to 105 cu. ft/sec.

The equipment of the power station consists of four units, three of these being installed at present (see Fig. 1). Each unit comprises a Pelton turbine built by the Ateliers des Charmilles, Geneva, direct coupled to a generator of 4500 KVA, 10,000 volts, 50 cycles, which works on the busbars through a step-up transformer for 10,000/64,000 volts. The whole power generated, apart from that required for the local supply, is transmitted by a single line to the switching and distribution station of the E. O. S. at Vorziers.

The 4500 KVA. generators are of the Oerlikon high-speed design. The rotor body is made of forged steel and the poles are fastened by means of claws inserted in round holes (see Oerlikon Bulletin No. 47) — a design which permits of the calculation and testing of stresses with great accuracy and of the exchange of pole and stator coils in the shortest time. The rotor was subjected at the Oerlikon

Works to an overspeed test at 1350 RPM. to the runaway speed of the machine. The stator had to be made in four parts in order not to exceed the maximum weight of 8800 lbs fixed by the clients, in view of the difficulties of transport. In order to permit of an adaptable supply, the plant was designed for a lower temperature rise at normal load than provided for in Standard Regulations. Furthermore, a pressure regulation of $\pm 10\,\%$ normal pressure was stipulated for all conditions of load. The efficiencies obtained at the acceptance tests proved to be considerably higher than laid down in the Specification. For instance, with a load of 4500 KVA and P. F. = 0.8, an efficiency of 95.35 % was obtained while an efficiency of 94.5 % with a tolerance of 1 % had been guaranteed. The current for the excitation is supplied in the case of each machine by an overhung exciter, and an automatic demagnetising switch is provided, by means of which the machine can be demagnetised.

The generators are protected only by overload relays which are mounted directly on the bushings of the oil circuit breakers in the high tension line. As, on the other hand, the synchronising is done on the 10 KV. side, neither current transformers nor potential transformers are required on the 64 KV. side. The overload relays on the 10 KV. and 64 KV. oil circuit breakers cause the release of the corresponding demagnetising switch, which in turn closes the circuit of the trip coils of the oil circuit breakers.

The protective equipment of the generating station is completed by an extinguishing coil, which is connected to the neutral point of the 64 KV. system. All other protective gear, such as would be costly in comparison with the price of the generators and transformers is dispensed with, as the power station is constantly under supervision. The omission of such gear was also partly justified by the fact that very severe testing rules were laid down for the generators and transformers.

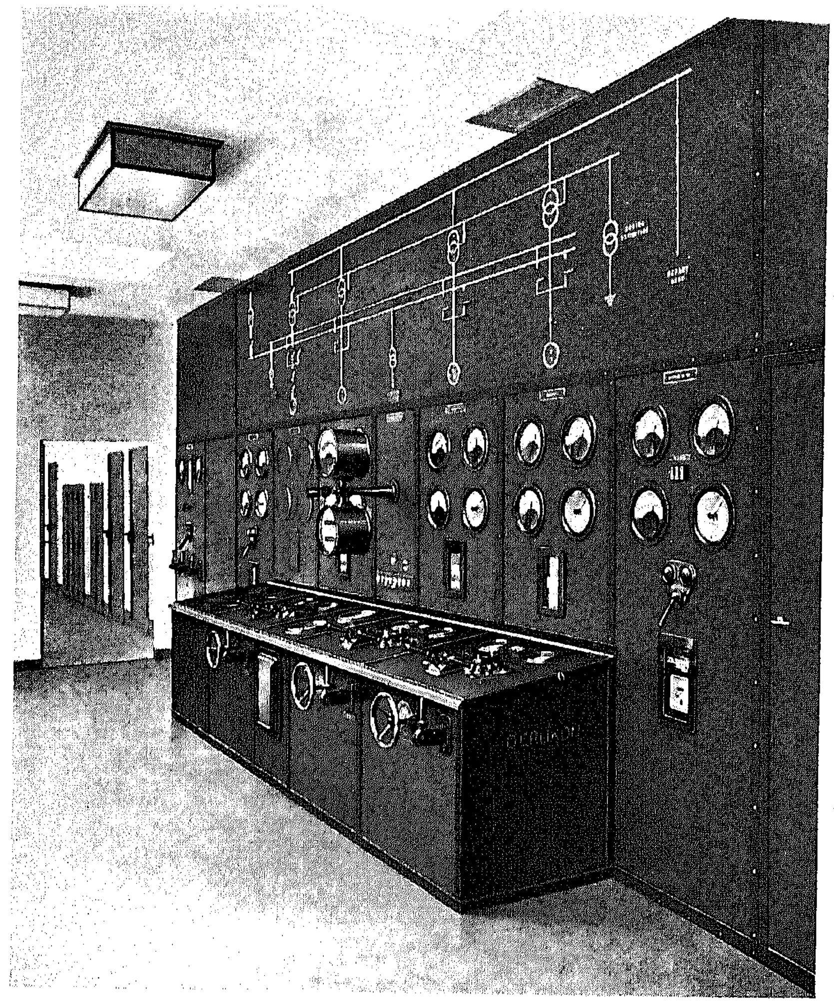


Fig. 2. Control desk and mimic busbar system.

All the oil circuit breakers of the generating station and also those intended for the local supply are provided with electric remote control (D. C. servo-motors).

The control panels are distributed on a switch desk with five panels (one panel for each generator and one panel for the parallelling and recording instruments). The desk is built on to a sheet metal switchboard, which serves for receiving the measuring instruments for the generators as well as the instruments and the master switches for the outgoing lines, the local distribution system and the auxiliary services. A mimic busbar system provided on the upper part of the switchboard makes it possible to ascertain at any time the mode of connection of the different units and of the outgoing lines (Fig. 2). It may further be mentioned that the local distribution system is fed through an induction regulator.

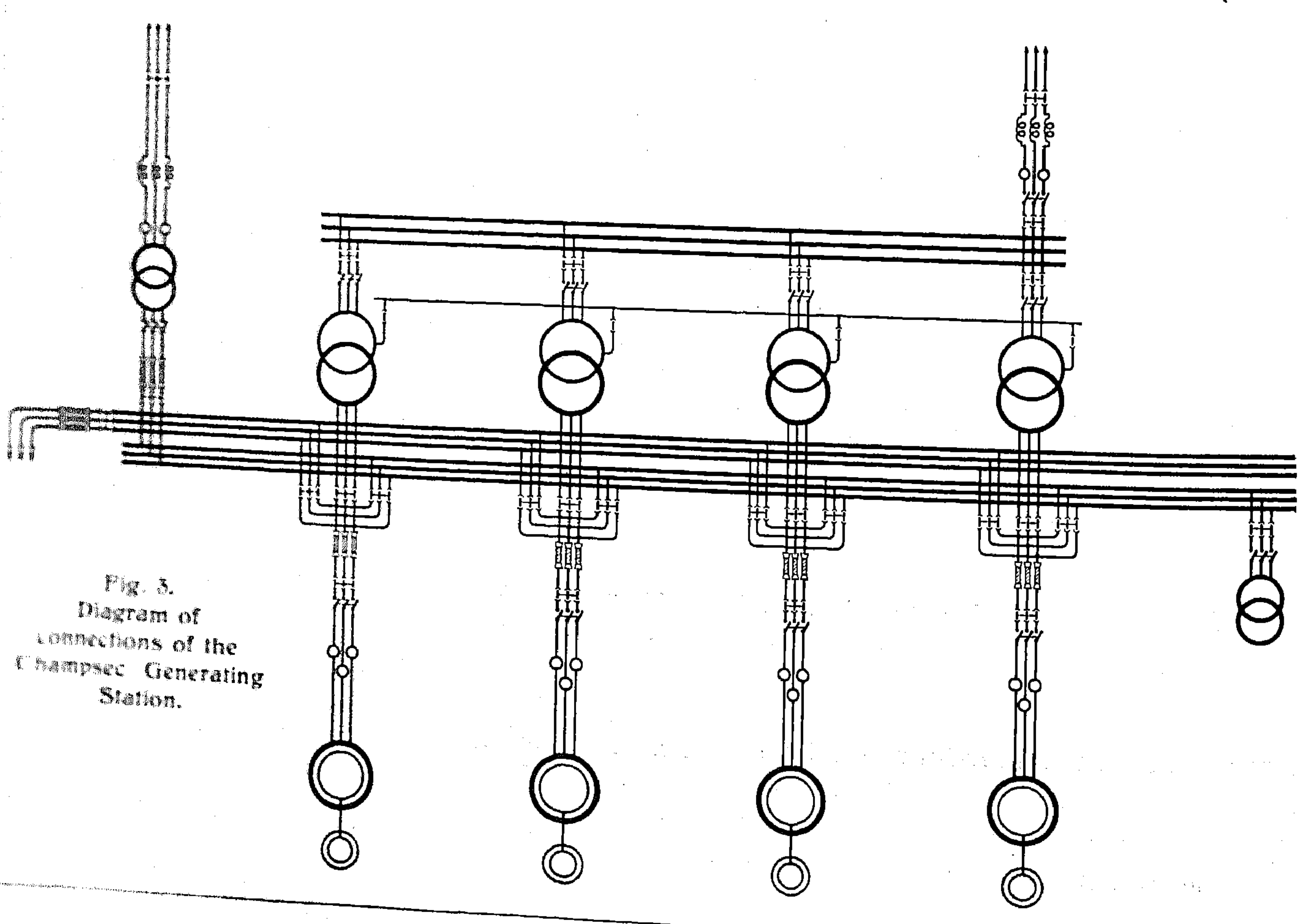


Fig. 3. Diagram of connections of the Champsec Generating Station.

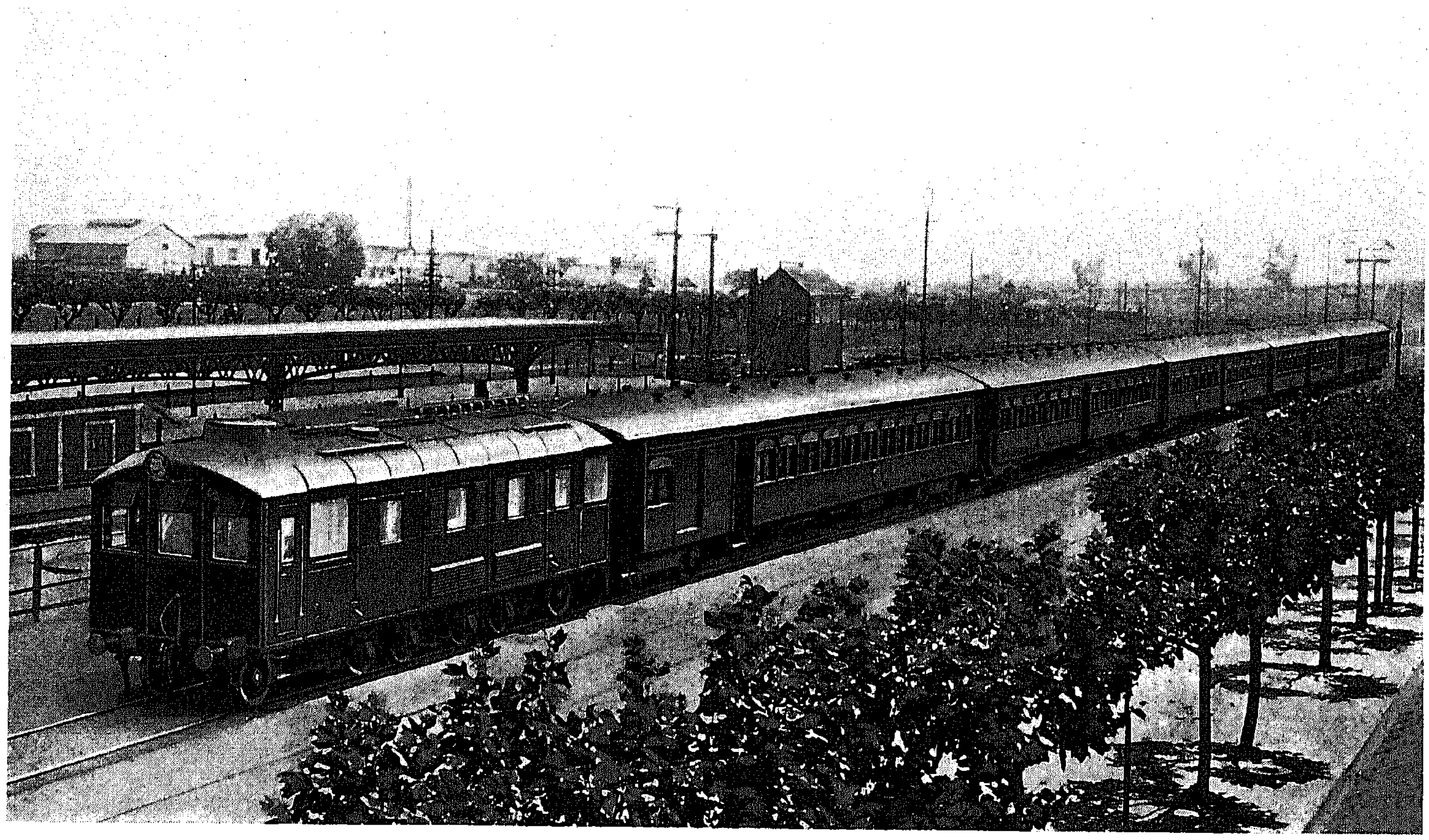


Fig. 8. Five-coach train with 600 HP. Diesel-electric locomotive of the Buenos Aires - Gt. Southern Railway.

Diesel-electric locomotives (Part II).

Buenos Aires - Gt. Southern Railway.

As a result of the very heavy increase in traffic on the Buenos Aires suburban lines, this railway company, which is financed mainly with English capital, was led to examine the possibility of using Diesel-electric locomotives in place of steam locomotives, for dealing with the traffic on these lines, which also include underground sections.

It is a well-known fact that the main consideration, in the case of suburban services, is the question of acceleration and retardation of the trains. In order to obtain, when starting, as high an acceleration as possible, the operating staff of the Buenos Aires-Gt. Southern Railway suggested the use of one or two Diesel-electric locomotives and eight to ten motor coaches, for the suburban trains, the traction motors being fed by the locomotives which were termed "travelling power houses". In 1927, the Oerlikon Company was entrusted with the task of preparing a detailed project for the electrical equipment, with a view to carrying into effect this original idea. The locomotive provided for was a locomotive consisting of two half locomotives equipped with two 600 HP. eight-cylinder Sulzer engines running at 700 RPM; the engines were each direct coupled to a generator capable of developing 365 KW, with corresponding exciter on the free shaft end. The pressure of the two generators was regulated by means of the controller, the excitation current of the generator being adjusted by the controller to suit the starting conditions and the speed of the train. Each of the two generators worked on a separate traction motor circuit, feeding one of the two driving motors of the locomotives and one of the two traction motors of the passenger motor-coaches, as can be seen from the diagram in Fig. 9. A complete train unit was to consist of one Diesel-electric locomotive at each end of the train, with ten motor coaches in between, all the axles being driven individually by traction motors. The train is arranged for multiple control from the leading locomotive. Two such double locomotives were ordered in first instance (see Fig. 8); the whole generating plant as well as the driving motors for all auxiliaries, i. e.

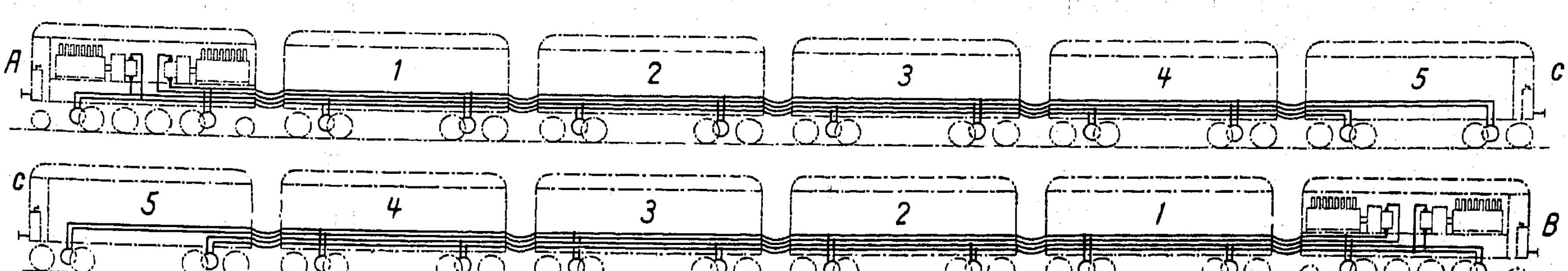


Fig. 9. General arrangement for multiple control, in the case of trains of the Buenos Aires - Gt. Southern Railway with Diesel-electric locomotives coupled to five motor coaches. A, B = Locomotive with double controller for control in the case of two five-coach trains. C = Motor coach with single controller for control in the case of one five-coach train.

for the blowers, for the coolers, for the cooling water and fuel pumps, were supplied by the Oerlikon Company; in the case of the fans for the blowers, it was necessary to build special 30 HP. vertical motors.

The other types of locomotives built for the Buenos Aires-Gt. Southern Railway are represented in the table on page 593; they do not present, however, any special features, apart from the fact that the shunting locomotive is provided with oil pressure gears for transmission purposes. In the case of the latter locomotive, the 64 KW. D. C. generator coupled to the Diesel engine serves only for feeding the auxiliaries and for charging the batteries, while it is also utilised as starting motor, the necessary current being then supplied by the auxiliary battery.

Appenzell Railway,

250 HP. motor coaches. The two motor coaches represented in Fig. 10 have been in service since the Spring of 1929. A detailed description of these motor coaches is given in Bulletin No. 99 of September 1929, so that we shall confine ourselves to giving a few supplementary data.

The Sulzer combustion engine is regulated at constant speed, the plant being adjusted for the conditions of service by varying the generator pressure. In order to permit of regulation over a large range of load, the Diesel engine is designed to run at two different speeds — 775 and 675 RPM; the higher speed corresponds to the continuous output of 250 HP. which can be exceeded to the extent of a 10% overload. The engine is changed over from one working speed to the other by means of electro-pneumatic valves, from the driver's cabs.

Fig. 11 shows the KW output of the generator during an outward and return journey, over the whole length of the line. It can also be seen from this diagram that the Diesel set is shut down on downgrade sections.

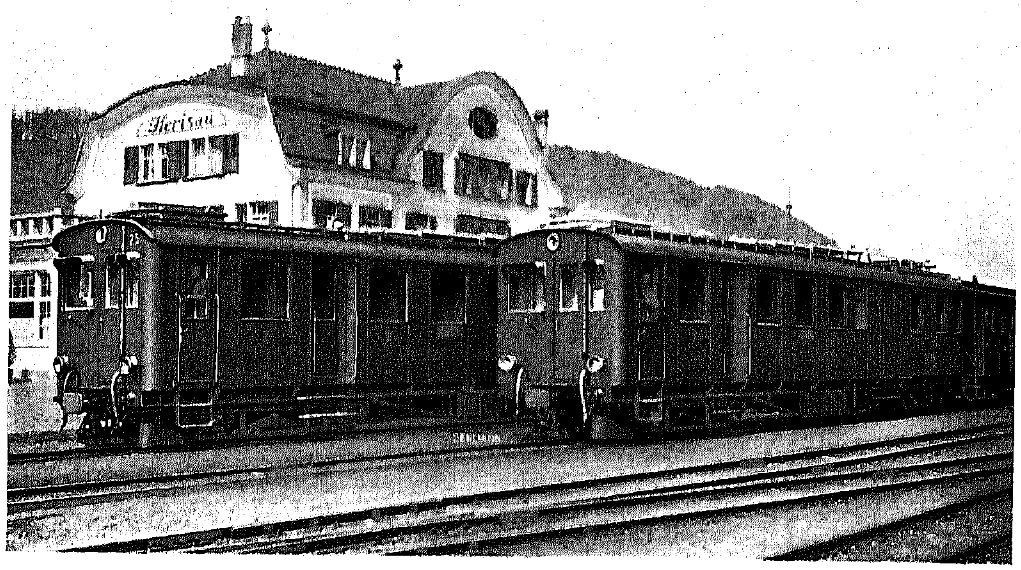


Fig. 10. Two 250 HP. Diesel-electric motor coaches of the Appenzell Railway.

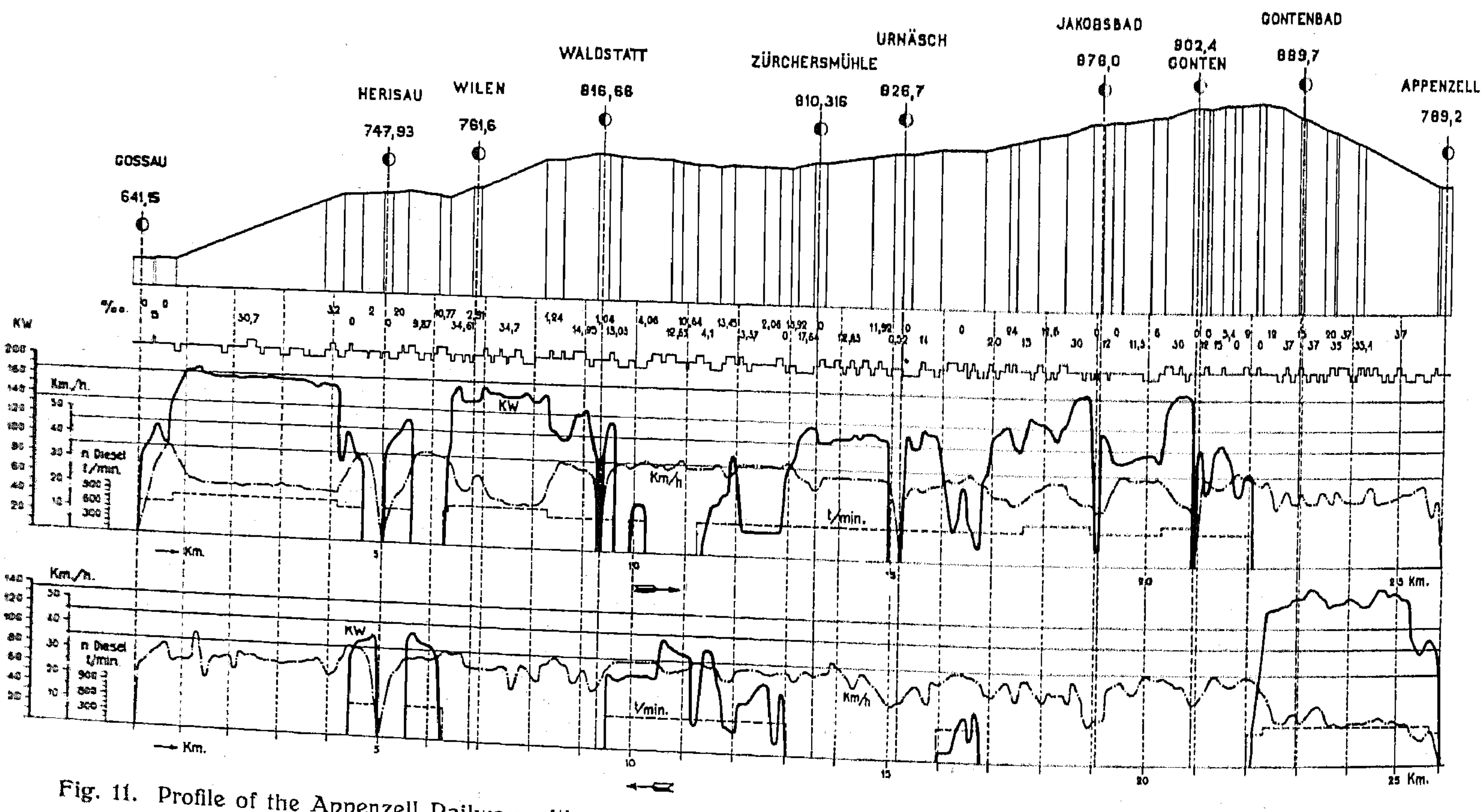


Fig. 11. Profile of the Appenzell Railway with speed and generator output charts for the outward and return journey.

Swiss Federal Railways.

420 HP. Motor Coach. This motor coach which was ordered by the Swiss Federal Railways from Messrs. Sulzer Bros, was put into service in the Spring of 1930. The mechanical part was built by the Swiss Industrial Co. of Neuhausen, while the whole electrical equipment was supplied by the Oerlikon Company. The motor coach is a four-axle coach (Fig. 12). The six-cylinder Diesel engine (see Fig. 15) is a four-cycle engine running normally at 630 RPM; it is direct coupled to a D.C. generator which carries on its shaft extension the armature of the auxiliary dynamo. The cooler for the Diesel engine is in the form of an air cooler mounted on the roof. The two traction motors are of the self-ventilated type with single reduction gear, having a ratio of 1 : 4.12; they are mounted on the opposite side of the motor coach to the Diesel engine set, so as to ensure a proper distribution of weight. The current for the excitation of the generator field is supplied by the auxiliary dynamo; the latter is provided with compound winding. The necessary current for the starting up of the Diesel engine is supplied by a 60-cell Ni Fe battery, having a capacity of 225 ampere-hours. The compressed air for the ope-

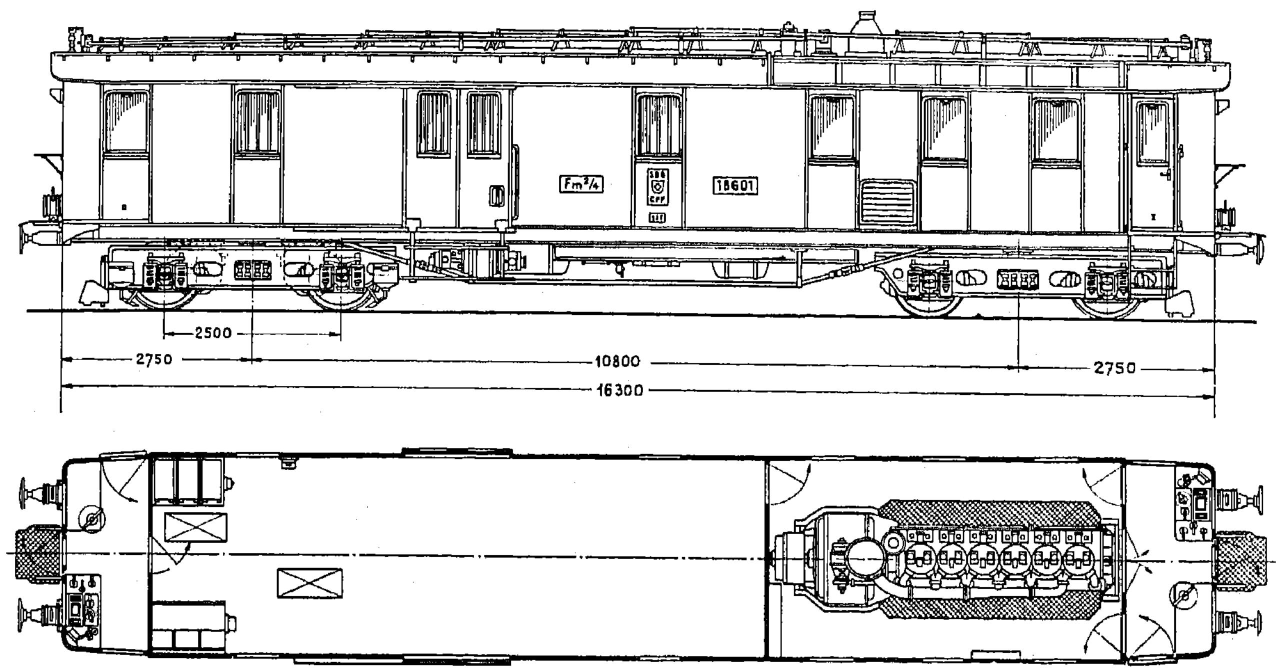


Fig. 12. 420 HP. Diesel-electric motor coach of the Swiss Federal Railways.

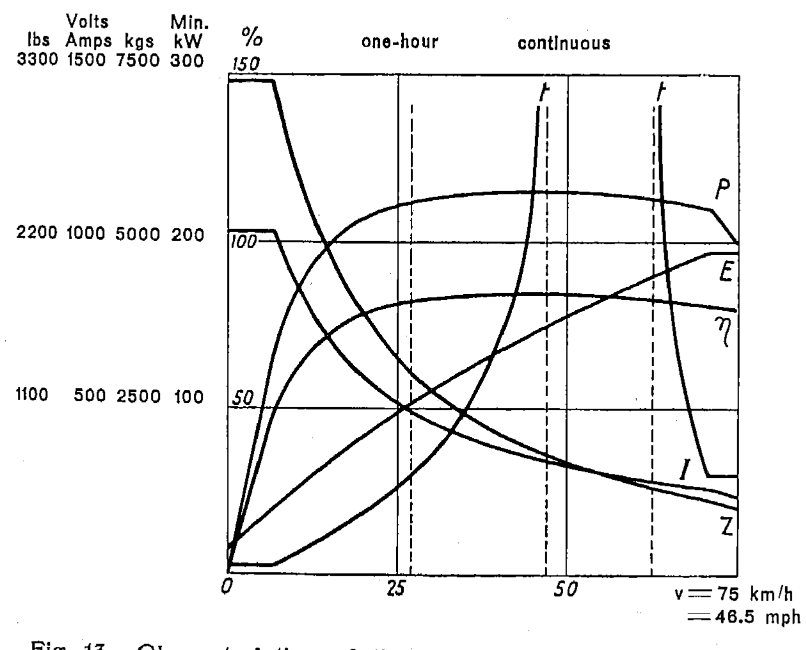
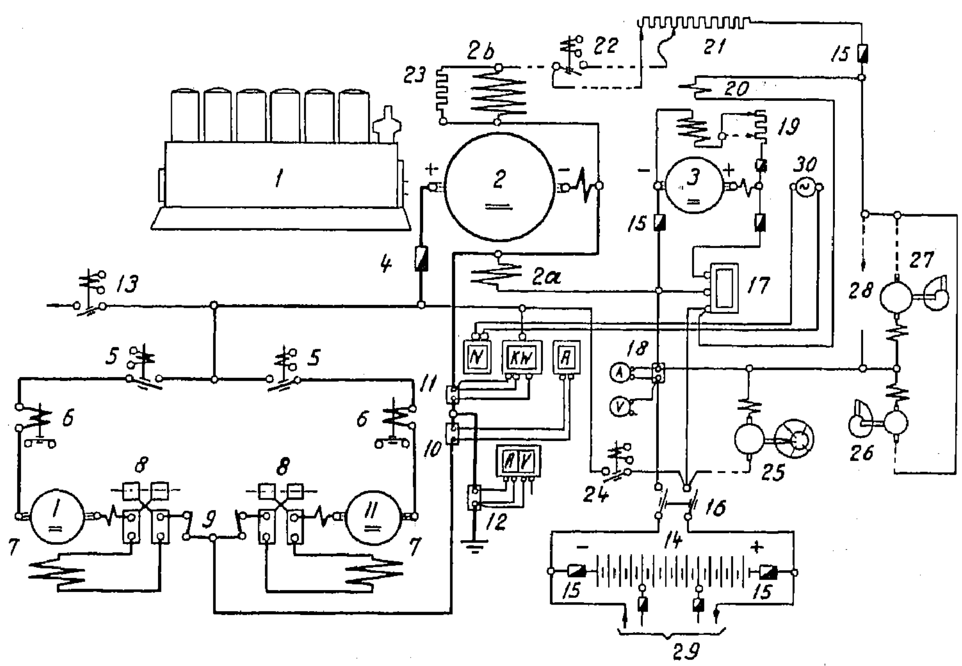


Fig. 13. Characteristics of the generator and of the two traction motors of the 420 HP. motor coach of the Swiss Federal Railways. The curves are plotted for an output of Diesel engine of 273+27 KW. at 6.5 to 72 km/hr (4 to 44 mph) and for a speed of generator and Diesel engine of 620 RPM).

I = Total current, in amps.
E = Generator pressure, in volts.
P = Output at wheel rim, in KW.
Z = Total tractive effort at wheel, in lbs.
t = Time, in minutes, during which the tractive effort corresponding to the full output of Diesel engine (230 KW) is developed.
η = Overall efficiency in % (Generator, motors and gears).

	Continuous rating	One-hour rating	
Current	340	490	amp.
Pressure	750	518	volts
Output	236 (320)	230 (312)	KW (HP)
Speed	47 (29)	27 (17)	km/h. (mph)

Two traction motors in parallel. Pressure 0—970 volts. Diameter of driving wheels 1040 mm (3′ 5″). Gear ratio = 1 : 4.12.


Fig. 14. Diagram of connections of the 420 HP. motor coach of the Swiss Federal Railways.

1 Diesel engine
2 Main generator
2a Starting field winding
3 Auxiliary generator
4 Generator fuse
5 Contactors of driving motors
6 Maximum current relay
7 Driving motor
8 Reverser
9 Isolating switch
10 Ammeter shunt
11 Wattmeter shunt
12 Ammeter shunt for train heating
13 Contactor for heating
14 Battery of accumulators
15 Fuses
16 Battery switch
17 Charging gear for battery
18 Ammeter shunt for battery
19 Field adjusting resistance
20 Compound winding
21 Field regulating resistance
22 Contactor for exciter
23 Protective resistance
24 Starting contactor
25 Compressor with motor
26 Cooling water pump with motor
27 Oil pump with motor
28 Controller
29 Lighting
30 Tachometer dynamo

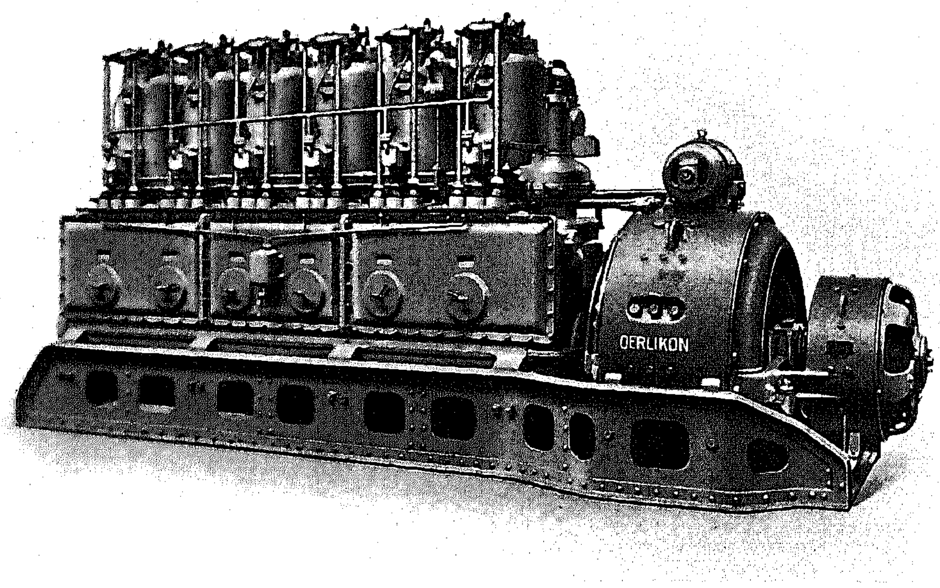


Fig. 15. Diesel generator set of the 420 HP. motor coach of the Swiss Federal Railways.

ration of the brakes and of the control gear is supplied by an Oerlikon motor compressor set. The motor driving the latter set can be run either off the auxiliary dynamo or off the battery. The characteristic curves for the transmission are plotted in Fig. 13, while Fig. 14 gives the general diagram of connections.

Main Particulars. Six-cylinder four-cycle Diesel engine. Output 420 HP. at 650 RPM. and output reduced correspondingly at 520 RPM.

Generator, type SB950, direct coupled. Maximum pressure 1020 volts.
Auxiliary dynamo, type GE45. Normal excitation pressure 150 volts.
Two traction motors, type EM520, with single reduction gear for a diameter of driving wheel of 1040 mm (3' 5").

Continuous rating	165 HP.	at	790	volts.
One-hour rating	156 HP.	at	540	volts.
One-hour rating	158 HP.	at	1020	volts.

Maximum speed	75 km/hour (46.5 mph).
Total weight of the electrical equipment without auxiliary battery	11650 kgs. (25680 lbs.).
Weight of the complete locomotive	56 tons.
Adhesive weight	24 tons.

South Manchurian Railways.

750 HP. Diesel-electric locomotive for standard gauge track. This Japanese Railway Co., which itself owns large locomotive and coach works at Dairen, has ordered in Switzerland and other countries, trial locomotives of the Diesel-electric type. The electrical equipment for a 750 HP. Diesel-electric locomotive has been ordered from the Oerlikon Co. through the intermediary of Messrs. Sulzer Bros. (see Fig. 16). It is intended mainly for shunting purposes within the harbour of Dairen (Dalny).

Main Particulars. 750 HP. eight-cylinder Sulzer-Diesel engine, normal speed 670 RPM., lower speeds, 570 and 470 RPM. One separately excited generator type 8 B 920, continuous rating, 445 KW. One auxiliary dynamo for 150 volts, direct coupled to the generator. Four self ventilated traction motors, type EM 520; continuous rating 135 HP. at 31 km/hour (19 mph); one-hour rating 155 HP. at 19 km/hour (12 mph).

Maximum speed 60 km/hour (37 mph).

Total weight of the locomotive 78 tons.

Auxiliaries:— Motor-compressor for delivering air at 70 to 85 lbs/sq. in. Output of the motor 25 HP. Two vertical blower motors, output 17 HP. at 2000 RPM., for the coolers, one cooling water pump, rating 3.5 HP. at 2300 RPM.

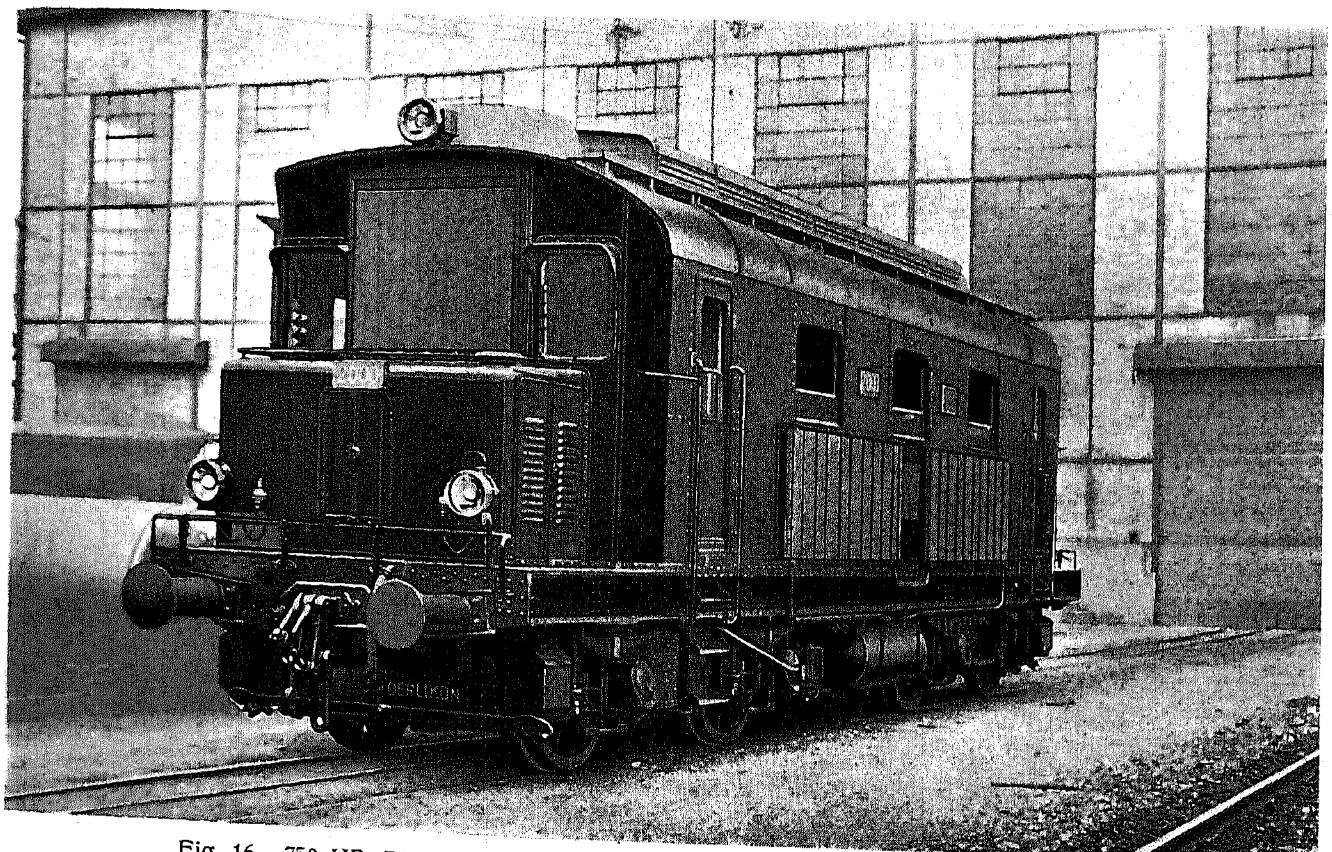


Fig. 16. 750 HP. Diesel-electric locomotive for the South Manchurian Railways.

Siamese State Railways.

a) One 1400 HP. double locomotive for freight and passenger trains, with 2 × 4 driving axles.

b) Six 900 HP. locomotives with four driving axles for express trains.

c) Six 450 HP. locomotives for passenger trains and for shunting purposes, with four driving axles.

d) Six 150 HP. motor coaches for local services with two driving and three carrying axles.

The securing of this order was a very creditable success for the Swiss Industry as, in spite of competition on the part of practically all large European firms, the contract for the electrical equipment for all the above-mentioned Diesel-electric locomotives, was placed with the Oerlikon Company, on the recommendation of the Chief Engineer of the Railway, Mr. Zachariae. In the case of the locomotives under a), b), and d), the combustion engines and also the mechanical part will be built by the Danish firm, Frichs Locomotive and Machine Works of Aarhus. The combustion engines and the mechanical part of the locomotives under c) have been ordered from Messrs. Sulzer Bros. of Winterthur. All the locomotives are to be delivered by July 1931. A detailed description of these locomotives will be published after completion of the contract.

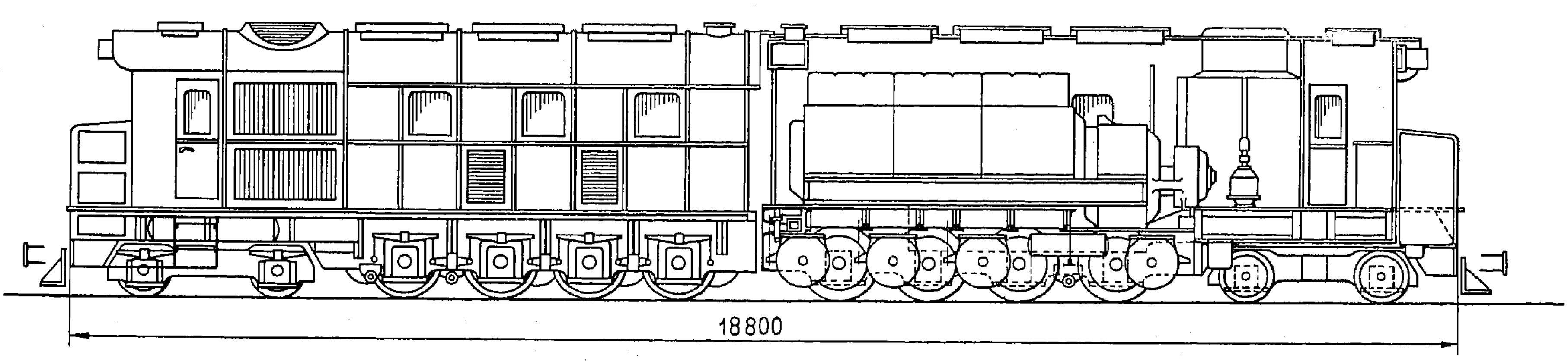


Fig. 17. 1400 HP. Diesel-electric double locomotive of the Royal Siamese State Railways.

a) 1400 HP. Double Locomotive (see Fig. 17).

Each of the two close-coupled locomotive halves is equipped with a 700 HP. Diesel engine with corresponding generator and auxiliary dynamo direct coupled to it. The normal speed is 600 RPM., with speed steps of 500 and 350 RPM. The 8 driving axles are each driven by a self-ventilated traction motor arranged for tram suspension, with single reduction gear for a diameter of driving wheel of 1050 mm (3′ 5.3″). The one-hour rating of each motor is 122 HP. at 21 km/hour (13 mph); the maximum speed is 45 km/hour (28 mph).

The 8 driving motors are controlled in the usual way, by regulating the generator pressure, this being done by altering the excitation of the generator by means of the master controller. The motors are connected in parallel in groups of 4 motors fed by one generator. The Diesel engines are adjusted for the three different speeds by means of electro-pneumatic Diesel control valves controlled by the master controller. The Diesel engines are started, as in the case of all locomotives and motor coaches previously described, by using the generators as starting motors, the current being supplied by an auxiliary battery. The plant is closed down by means of an electro-pneumatic valve which interrupts the fuel supply.

In view of the fact that the locomotive is to operate in a tropical climate, the fans for the coolers of the Diesel engines had to be very amply dimensioned. It is a well-known fact that, in the case of a Diesel engine, about one-third of the heat contained in the fuel is converted into useful work, one third is carried away with the combustion gases and the other third is led away with the cooling water. The cooler has, therefore, to dissipate as much heat as that corresponding to the useful output. It is thus necessary to dissipate about 2575 B. Th. U's per HP.-hour; this means in the present case, where we have a 1400 HP. locomotive, about 3,600,500 B. Th. U's.

A separate cooler, cooled by means of two fans, is provided in the case of each Diesel set, the fans being driven by 20 HP. vertical motors. These fan motors are fed directly from the exciter and are of the self-excited type.

The auxiliaries further include two vacuum pump sets for the brake, a small compressor for the production of the compressed air for the operation of the control gear and of the whistle, and two cooling water pump sets, which come into operation automatically when starting up the Diesel set.

b) 900 HP. Locomotives.

These six locomotives which were ordered for express train service, are likewise equipped with two Diesel sets; they do not, however, consist of two half locomotives, as in the case of the 1400 HP. locomotive, but both sets are arranged on a fixed locomotive frame, the driving wheels having a fixed wheel base. The power is transmitted here to four traction motors in all; the latter are arranged in groups of two motors fed by a generator. The design of the electrical equipments is essentially the same as in the case of the 1400 HP. locomotive.

The three speeds obtainable with the Diesel engine are, as in the case of the 1400 HP. locomotive, 350, 500 and 600 RPM.

The two vertical motors for the blowers of the cooler have each an output of 20 HP.; they are connected in the same manner as on the freight locomotive. A notable feature, both in the case of the 1400 HP. locomotive and of the 900 HP. locomotives, is the very compact arrangement. It was a difficult task, both for the locomotive builders and for the electrical designers, to arrange for these relatively large outputs for meter gauge locomotives, in the space available, without affecting the accessibility of the individual machine parts.

c) 450 HP. locomotives.

These six locomotives, which are equipped with Sulzer-Diesel engines, are built as bogie locomotives; they are primarily intended for dealing with passenger traffic. The Sulzer-Diesel engine has an output of 450 HP. and can be run at 700, 600 and 500 RPM. The normal train speed is 21 km/hour (13 mph) and the maximum speed 60 km/hour (37 mph).

The maximum pressure of the electric transmission system is 780 volts. The four motors, type EM 42, have each a one-hour rating of 80 HP. at wheel rim, the diameter of wheels being 1000 mm (3′3.3″). The cooler is provided with two fans, the latter being driven by 12 HP. D.C. motors. The cooling water pump is direct coupled to a 2 HP. D. C. motor.

The pump set for the vacuum brake consists of an Oerlikon vacuum pump capable of dealing with a quantity of air of 2000 litres per min. (70.6 cu. ft.) driven by a 4.6 HP. D. C. motor. The speed of the latter motor can be regulated in three steps. There is further a small compressor set for the production of compressed air for the electro-pneumatic control.

d) 150 HP. motor coaches for suburban services.

These six motor coaches are intended exclusively for dealing with suburban traffic. The motor coaches are five-axle motor coaches, i.e. they are fitted with one three-axle bogie at the Diesel engine end and with one two-axle bogie at the other end of the motor coach. The latter bogie is equipped with two traction motors. The motor coach has a dead weight of 40 tons and can accommodate 56 passengers. There is, further, a large luggage compartment next to the machine room. The Diesel engine has an output of 150 HP. at the normal speed of 700 RPM., while at 600 RPM., the output is reduced accordingly. The two traction motors are of the self-ventilated type and designed for a maximum train speed of 28.5 mph; the one-hour rating of each motor is 50 HP. measured at shaft, and the maximum working pressure 510 volts. The motors work permanently in parallel. The mode of control is essentially the same as in the case of the locomotives under a) to c) and the auxiliaries are similar to those of the larger types of locomotives, the capacity of the plant being such as to correspond to the lower output of the motor coaches.

Puerto di Rosario (Argentine Republic).

Three shunting locomotives for 1676 mm (5′ 5.9″) gauge track. Output of Diesel engine 330 HP. six-cylinder type, normal speed 706 RPM. with speed steps of 600 and 500 RPM.

The generator, which is separately excited by an auxiliary dynamo is wound for a maximum working pressure of 600 volts. The four traction motors are of the self-ventilated type and built to the following data: Output of each motor (continuous rating) 58 HP. at 12.8 km/hour (8 mph)

Tractive effort (continuous rating) 1390 kgs (3604 lbs) at wheel rim (diameter of wheel 914 mm = 3′)

Tractive effort (one-hour rating) 1925 kgs (4235 lbs) at wheel rim. at 8.7 km/hour (5.4 mph)

Tractive effort when starting 3500 kgs (7716 lbs) per motor, total 14,000 kgs (30864 lbs)

The maximum speed is 45 km/hour (28 mph).

Electro-pneumatic control is used here, as in the case of all the designs previously mentioned.

The following auxiliaries are provided:—

For the cooler, one blower motor with an output of 17 HP., for a terminal pressure of 145 volts and a speed of 2000 RPM.

One cooling water pump motor.

One motor compressor set for the compressed air brake and for the operation of the apparatus.

The locomotives have two driver's cabs each equipped with a complete set of apparatus and measuring instruments.

It can be seen from the foregoing that Diesel-electric locomotives and motor coaches are suitable for the most varied traction purposes. On the one hand, they can be used for heavy as well as light suburban trains (Buenos Aires-Gt. Southern Railway) where high acceleration at starting is required, while they can also be utilised as heavy freight locomotives and, furthermore, as shunting locomotives (South Manchurian Railways).

On the other hand, if we take the motor coaches of the Appenzell Railway and the Diesel-electric locomotives of the Siamese State Railways, we see that this traction system is suitable both for local lines with small power requirements and for State Railways with express and freight services. In the case of the Siamese State Railways, purely electric traction would have been hardly practicable, owing to the difficulties in running a conductor line through tropical virgin forests; but even in districts where there are no technical difficulties in connection with the provision of a conductor line, there are certain cases, for instance, when the limited traffic density does not justify the laying of a conductor line, where the absence of the latter is a factor in favour of the use of Diesel-electric locomotives.

Traction with Diesel-electric locomotives permits, in every instance, of a saving in operation costs as compared with steam traction, owing to the very much better utilisation of the heat of the fuel. A further advantage resides in the fact that such locomotives are immediately ready for service. In the case of railways with gradients exceeding 1 in 100, it is, furthermore, possible to shut down the Diesel engine during downgrade runs, so that a considerable saving in fuel is thus obtained. It is also possible to connect the traction motors in such a way as to permit of short-circuit braking during downgrade runs. The various advantages can be briefly summarised as follows:—

1) The cost of fuel is only a small fraction of that in the case of operation with steam.
2) The amount of water required is very small as the cooling water for the Diesel engine is cooled down after passing through the latter and used over again.
3) The locomotive is ready for use within a few minutes.
4) Suitability for one-man operation.
5) Greater cleanliness in service, as with purely electric locomotives and, consequently, lower cleaning costs.
6) Rapid and easy refuelling.
7) Lower cost of fuel and very much less space required for storing it, than in the case of coal.

The Diesel-electric locomotives are, therefore, at the present day in a position to replace steam locomotives in every respect. In certain cases, for instance, when the density of traffic is small or the cost of electric energy high, or finally, when there are technical difficulties in connection with the provision of a conductor line, this traction system presents advantages even over purely electric traction.

It is the task of the engineer dealing with projects to weigh the advantages of the two systems, as the case arises, and to put forward the more advantageous solution from a technical and economical point of view.

ATELIERS DE CONSTRUCTION OERLIKON, OERLIKON

BULLETIN OERLIKON

No. 119 — May 1931

Contents: Three-phase four-winding transformers for the Ryburg-Schwörstadt Power Supply Company, Rheinfelden.
Losses in the blading of axial impulse turbines, due to partial admission.
Emergency governors on Oerlikon steam turbines.

Dimensions of transformer.

Maximum length 8700 mm (28′6″)

Maximum width 5400 mm (17′8″)

Height up to the top of terminals 8900 mm (29′2″)

Height up to crane hook, about 14,000 mm (45′10″)

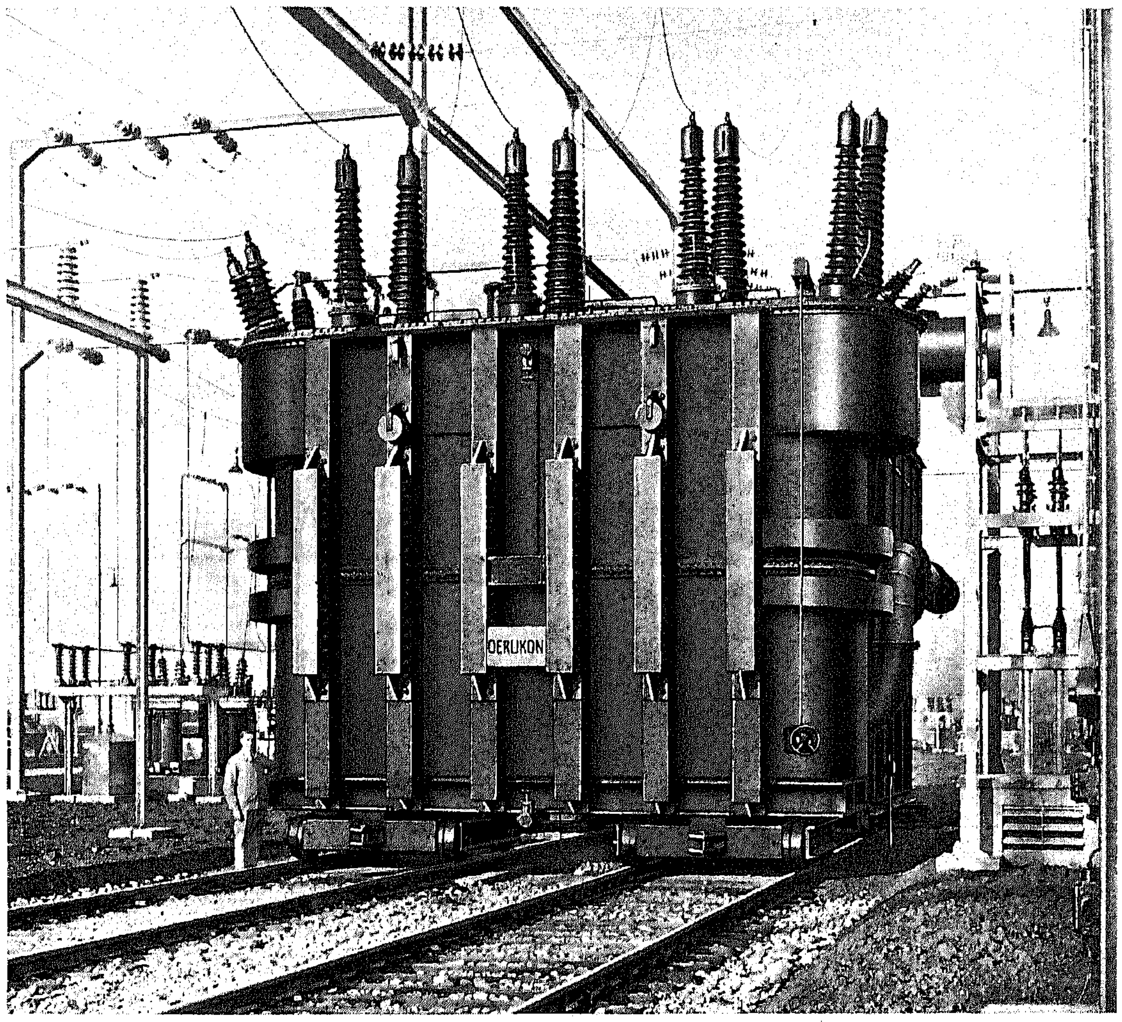


Fig. 1. Complete transformer in service.

Weights.

Transformer complete without oil about 155 tons.

Weight of oil for the transformer 55 tons.

Cooler complete without oil 40 tons.

Oil for the cooler 17 tons.

Three-Phase Four-Winding Transformers for the Ryburg-Schwörstadt Power Supply Company, Rheinfelden.

In Oerlikon Bulletin No. 113, a few particulars were given regarding the requirements these transformers have to satisfy. We now propose to deal somewhat more in detail with the design of these rather unusual transformers. The main data of the three-phase transformers in question are briefly as follows:—

Capacity of each of the four windings 32,500 KVA.
Continuous overload capacity of each of the four windings up to at least 35,000 KVA.
No-load pressure ratio 10.5 KV/48—116±5%—145±5% KV.
Frequency 50 cycles.
Connections 10.5 KV, delta;
48, 116 and 145 KV, star with insulated neutral point brought out.

This means that when all four windings are loaded at the same time, 70,000 KVA can be transformed in such a unit.

1) Iron core. The transformers are of the core type; they have three limbs and are designed with butt joints between limbs and yokes. The iron core is built up of 1.6 watt laminations 0.4 mm thick, with glued on paper coating. As the maximum length of laminations for electric machinery supplied by European steelworks is 2600 mm (8′6″), the limbs alone could be made of one length of lamination. The yokes, which have a length of nearly 5 m. (16′5″) had, therefore, to be made of two lengths. The joints of the laminations are arranged away from the centre of yoke and the different layers of laminations are interleaved so that the yokes, in spite of their great length, constitute a single compact body.

In order to avoid burnt spots in the core, special care has been taken with a view to ensuring a good insulation of the whole of the iron core, and all parts of the

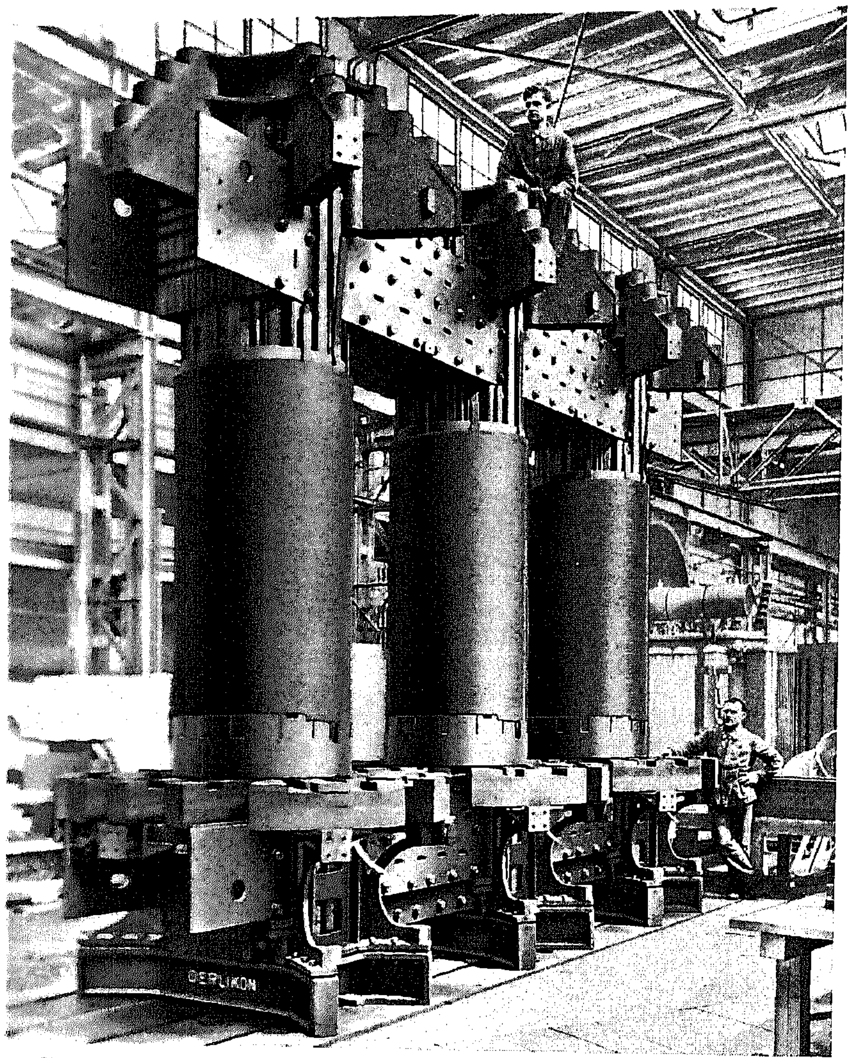


Fig. 2. Transformer during erection (iron core and iron frame).

insulation have been carefully tested. The importance of these precautions will be easily realised, if it is borne in mind that the pressure induced by a single turn, in the iron body, amounts to as much as 140 volts.

It was further important that the iron core should form a firm compact body which whould retain its strength, even after a long period of service. With this object in view, the different parts of the iron core, in addition to being subjected to a heat treatment in an oven, were pressed with a large hydraulic press, permitting of a pressure up to 400 tons. Both the laminations of the limbs and of the yokes are held together by means of powerful tie rods and cover plates. The latter are made of non-magnetic material with a view to avoiding additional losses and local heating due to eddy currents. The iron losses can reach a value of 250 KW. in the case of the maximum pressure. In order to dissipate this large quantity of heat and to keep the temperature within permissible limits, provision is made, in each limb, for three cooling slots disposed in a perpendicular direction to the layers of laminations. The yokes have also cooling slots in a transversal direction to the layers of laminations; these are, however, of small dimensions, as the density of flux in the yoke is about 15% smaller than in the limbs, and the losses are reduced accordingly.

2) Iron Frame. The two yokes are pressed against the limbs by means of strong tie rods and cast steel cross pieces; the pressure is exerted at three points immediately above each of the limbs. This ensures a perfect contact between yokes and limbs and reduces the humming and vibration of the transformer to a minimum. The lower cross pieces are fitted with rests which constitute, together with the yoke, strong supporting surfaces for the winding. The upper cross pieces are built in the form of frames with radial projections and serve, at the same time, for pressing the different windings. The above details are, in most part, visible in Fig. 2, which represents the transformer during erection.

3) Windings. The arrangement of windings was fixed by the condition laid down that the ratio between the various short-circuit pressures should not be higher than 1:2. We have first, next to the core, half the 10.5 KV. winding, then follow, radially, the 116 KV, the 48 KV, the 145 KV and finally the second half of the 10.5 KV. winding, which constitutes the outermost winding. We thus have a double concentric winding which comprises, however, three H. T. windings instead of one H. T. winding between the two low-tension halves.

The coils are circular, this being the shape which gives the coils the greatest mechanical strength to withstand stresses in the case of short-circuits. Both coils of the 10.5 KV. winding are wound in one layer. As the copper strip used is only 12 mm wide, the coils had to be bandaged in quite a special manner, in order that they should have sufficient mechanical strength, in spite of the very large dimensions of coils.

The H. T. windings are built up of individual sections of coils, in the usual way, with amply dimensioned oil channels between the individual sections. The conductors of the H. T. windings are insulated throughout with special paper. The insulation has been dimensioned in such a way that, in the case of the initial turns, the winding is capable of withstanding, for a short time, between conductors, the full terminal pressure, while the other turns with normal insulation can withstand about 60% of that pressure. The two ends of the 116 and 145 KV. coils are provided with electrostatic protective rings. The object of these rings is to flatten out pressure surges and to reduce the stresses in the insulation, from turn to turn, in the case of high frequency pressure variations through capacity charges in the individual turns, and to decrease the electro-static field. As shown by experience, a transformer insulated in this way can be regarded as safe against pressure surges and can actually be connected, without H. T. protection, even to an extensive system. After the coils had been finally assembled together, they were carefully dried out in an oven and impregnated with an entirely oil-proof insulating varnish. In this way, it has been possible to obtain coils which are very strong mechanically, very compact, only little hygroscopic and very resistant against the action of oil acids. The insulation between windings is ensured by ample oil channels and bakelised paper cylinders, two insulating cylinders being provided on both sides, in the case of the 116 KV. winding, and three, in the case of the 145 KV. winding. The test pressures applied to the 10.5, and 48, 116 and 145 KV. windings were 57, and 104, 269 and 324 KV. for one minute.

Special attention has been paid to the pressing of windings. In order that all five concentric coils of a limb should be subjected to a uniform pressure, in spite of the differences in their design, each coil is pressed independently against the rests on the lower yoke by means of

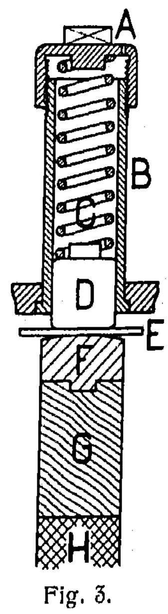


Fig. 3. Oil dash-pot for pressing the windings.

six powerful steel springs, evenly distributed along the periphery, and wrought iron press rings. In order to take the stress off the springs, in the case of heavy axial impacts due to short-circuits, the Oerlikon Company have adopted a special design which has given very good results for many years and under the most severe conditions of service. This constructional detail, which is of considerable importance, is shown in Fig. 3. The spring is arranged in a tube; it presses against the wrought iron press ring and the winding, through the intermediary of a piston. The spring is compressed by means of a nut at the other extremity of the tube. If the winding settles somewhat, in the course of time, the piston moves a little out of the tube and oil can penetrate into the cylindrical chamber through a small hole in the nut. In the event of an impact due to a short-circuit, which latter acts, at least with its greatest force, only for a very short time, the oil cannot escape rapidly through the small hole, so that the piston cannot move up. Exhaustive tests have shown that an oil dash-pot of this design is very effective in practice and contributes very materially to the greater security of plant against short-circuit stresses. These oil dash-pots are built directly into the press frame. It is very important, specially for transformers of the size in question, that the winding supports should be very carefully designed, as overhauling can only be carried out very seldom, owing to the very great disturbances this causes in the service. The bushings are a combination

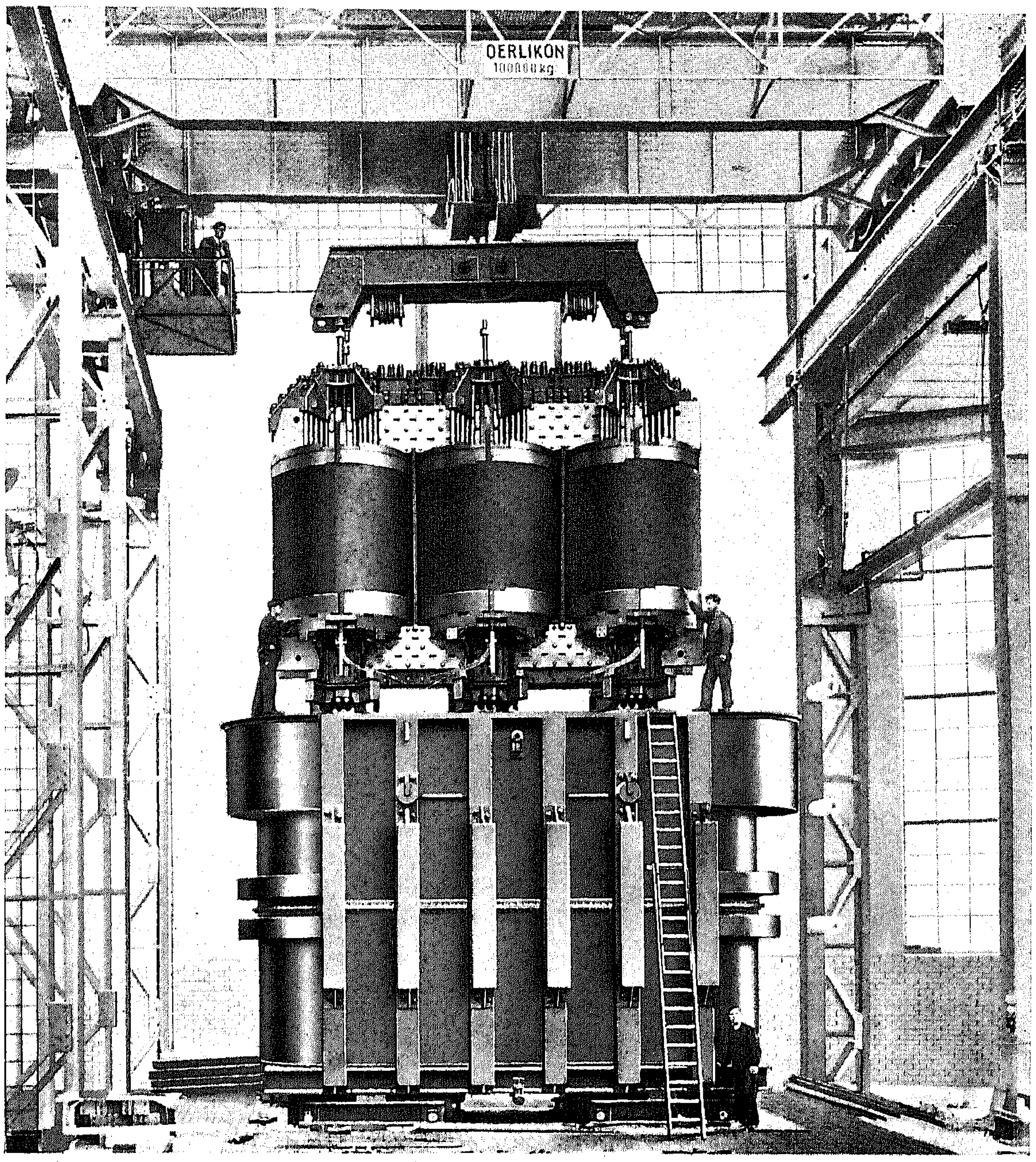


Fig. 4. Transformer suspended to the crane during erection.

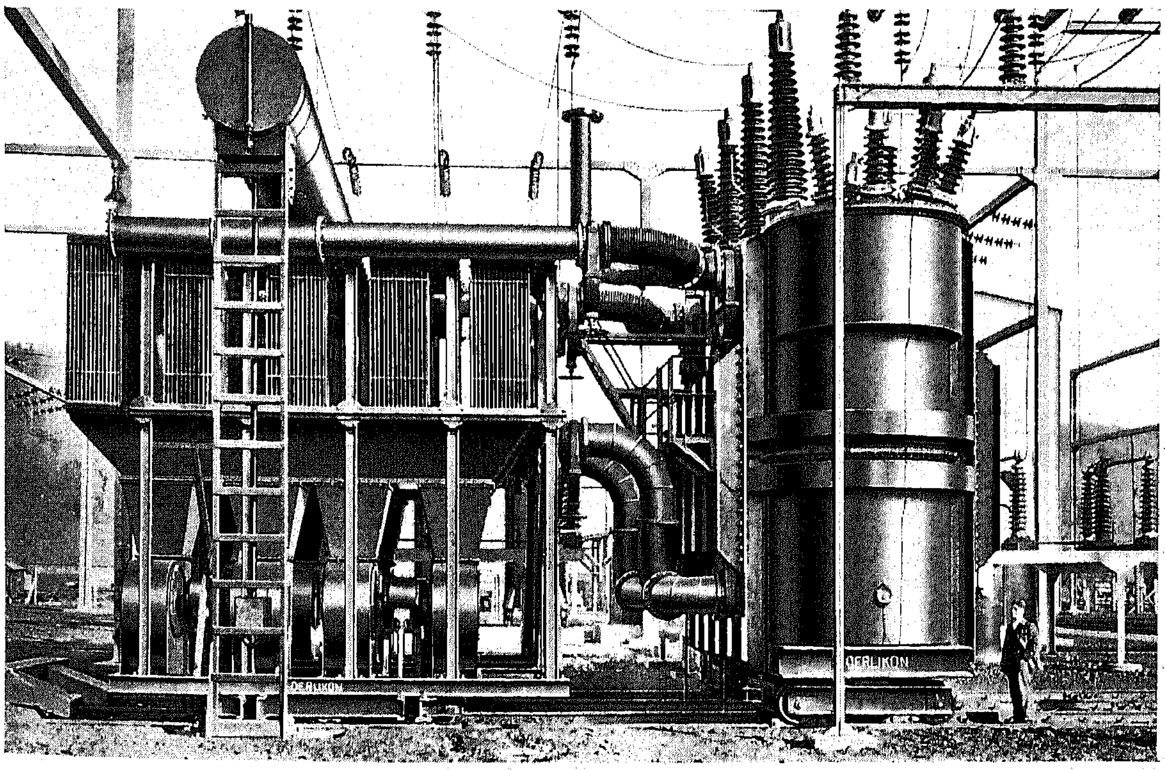


Fig. 5. Transformer with connected-up cooler in service.

of the usual oil-filled type and of the condenser type. The distribution of potential in a radial and axial direction is very good so that there are no discharges right up to the point of flash-over. The test pressures applied to the different bushings under damp conditions were 73, 135, 315 and 375 KV. It was no easy matter to fit the 15 bushings on the cover. The 145 and 116 KV. bushings are arranged on the two wide wides, together with the corresponding neutral points, and the 48 and 10.5 KV. bushings on the narrow sides. The oil tank is built in such a way as to render it capable of withstanding vacuum; it is made in two parts for reasons of transport. The tank rests on two under-carriages with eight rollers in all, having a diameter of 500 mm (1'7").

Losses in the Blading of Axial Impulse Turbines, due to Partial Admission.

When converting energy in turbines with partial admission, there is a loss item to be reckoned with, which is not encountered in the case of turbines with full admission. This loss item comprises all losses which occur at the edge of the steam jet due to the runner blades continuously entering it and leaving it. We shall endeavour, in the following, to determine these losses by calculation, in the case of axial impulse turbines.

In Fig. 1, we have represented in a section through the turbine along the surface of a cylinder concentric with the axis of turbine and corresponding to the mean circle of admission, a steam jet with a width s which drives a weight of steam G per second into the runner. The runner, as it revolves, carries along in its blading a stagnant volume of steam with a weight G' per second, which, on one side of the stream of steam, mixes with the latter and, on the other side, separates from it. The border zone of the steam jet, with a width, s_e, takes part in this mixing process with the steam carried along in the runner, while the second border zone, with a width, s_a, includes a quantity of steam with a weight G' which is detached from the steam jet by the runner blading. There is a quantity of steam with a weight G_m, which is not unfluenced by what occurs at the edge of the steam jet and, consequently, in the case of which the velocity diagram in Fig. 2, holds good. The designations used in Fig. 2 for the velocities and angles are those utilised in the following calculations.

It is assumed that the inlet and outlet angles of the runner blades are equal and that the latter are symmetrical in relation to a plane perpendicular to the axis of rotation.

Let us designate by h the height of steam jet in a radial direction, this height being also taken as equal to the height of the runner blades, and by v the specific volume of the steam which is assumed to remain unaltered. We then have, for an axial width b of runner blades, the following weights of steam per second:

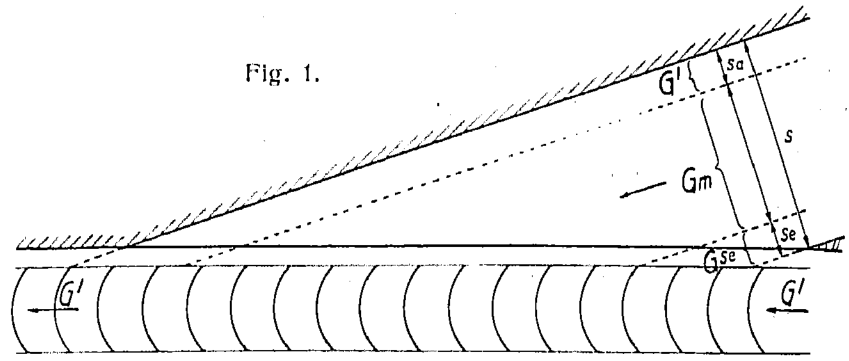
$$G = \frac{s \times h \times c_1}{v} \qquad G' = \frac{n \times b \times h \times u}{v} \qquad G_{se} = \frac{a \times s \times h \times c_1}{v}$$

$$G_m = (1-a)\, G - G' = \frac{h}{v}\Big[(1-a) \times s \times c_1 - n \times b \times u\Big]$$

In these expressions, $a = \frac{s_e}{s}$ and n is a figure giving the ratio between the weight G' and the maximum value $\frac{b \times h \times u}{v}$ the latter can reach in the ideal limit case. This maximum value would have to be introduced, for instance, if the runner blades were infinitely thin. The power supplied to the runner by these quantities of steam will be designated in each case as follows:—

L_n = Power from the whole steam jet with a weight G under undisturbed conditions of operation.
L_m = Power from the central steam jet with a weight G_m.
L_e = Power from the steam G' brought along by the runner on the side where the runner blades enter into the steam jet.

Fig. 1.



L_a = Power from the steam G' taken by the runner from the steam jet on the side where the runner blades leave the steam jet.
L_{se} = Power from the steam G_{se} of the border portion of the steam jet on the side where the runner blades enter into the steam jet.

Owing to the partial admission, there is a reduction in power, the ratio ν_r between the reduced power and the maximum power L_n in the case where the weight of steam G works under undisturbed conditions being:

$$\nu_r = 1 - \frac{L_m}{L_n} - \frac{L_e}{L_n} - \frac{L_a}{L_n} - \frac{L_{se}}{L_n} \quad . \; . \; . \; . \quad (1)$$

The power supplied by the whole steam jet with a weight G, working in accordance with the diagram in Fig. 2 is given by the expression:

$$L_n = \frac{G}{g}\Big[(1+\psi)\, w_1 \cos a_1\Big]\, u$$

In this formula, ψ is the velocity loss coefficient in the runner. The central steam jet with a weight G_m works also according to the diagram in Fig. 2; consequently, the power it supplies is:—

$$L_m = \frac{G_m}{g}\Big[(1+\psi)\, w_1 \cos a_1\Big]\, u$$

The quantity of steam G' carried along in the runner comes into contact with the border portion of steam jet with a weight G_{se} and mixes with the latter so that these two quantities of steam leave the runner with a common relative velocity w'. The velocity diagram for the quantity G' is plotted in Fig. 3. The velocity w', after the mixing of the quantities of steam G' and G_{se}, has the value $w' = \frac{G_{se} \times w_1}{G_{se} + G'}$ and the power L_e from the steam G' is given by the expression:

$$L_e = \frac{G'}{g}\Big[w' \cos a_1\Big]\, u$$

On the side where the runner blades leave the steam jet the quantity of steam G' works in accordance with the diagram in Fig. 4 and supplies to the runner the power L_a given by the expression:

$$L_a = \frac{G'}{g}\Big[w_1 \cos a_1\Big]\, u$$

In the case of the border portion of jet with a weight of steam G_{se}, the velocity conditions are as plotted in the diagram in Fig. 5. The steam G_{se} supplies to the runner the power L_{se} given by the expression:

$$L_{se} = \frac{G_{se}}{g}\Big[w_1 \cos a_1 + w' \cos a_1\Big]\, u$$

If we take these various amounts of power and introduce them in the formula (1) for v_r and replace the weights of steam by their value in function of the dimensions of the turbine as given above, we obtain the following formula for v_r:

$$v_r = \frac{1}{1+\psi}\left[\frac{b}{B}\times m\times\psi\times\frac{u}{c_1}-\alpha(1-\psi)\right] \quad . \quad . \quad (2)$$

In this formula, we have introduced the quantity m in place of the expression $n/\sin\alpha_0$. In order to be able to apply this formula to a turbine of the above dimensions, it is still necessary to have the quantities α or s_e. These quantities depend upon the depth to which the steam jet is disturbed by the weight of steam G', when the runner blades enter the steam jet. This depth is limited owing to the presence of runner blades. It can be determined as follows:

The steam in the border zone of the jet, with a weight G_{se}, moves with a mean relative velocity $\frac{w_1+w'}{2}$ through the runner. A particle of steam on the edge of the jet describes, when passing through the runner, the absolute path A shown in Fig. 6. It thus travels a distance U along the periphery of the wheel. In the case of the position of runner blade indicated in Fig. 6, the quantity of steam penetrating into the channel 2 of runner would just no longer be affected by the steam G' carried along by the runner. There is, however, a possible influence at the moment when the blades have not yet reached the position indicated. In any case, the disturbance cannot extend as far as the channel 3 of runner. We are, therefore, justified in making the assumption:

$$s_e = \alpha\times s = (U+t)\sin\alpha_0 \quad . \quad . \quad . \quad . \quad . \quad (3)$$

In this expression, t, which is the distance between two runner blades, is independent of α, while U is dependent upon α, as this quantity appears in the expression for w'. While the particle of steam describes the relative path fixed by the profile of the runner blade, with the mean velocity $\frac{w_1+w'}{2}$, along the runner, the runner blade moves forward through a distance U. We can now obtain, on the strength of this relation and under the assumption that the relative path corresponds to an arc determined by the chord b and the angle α_1, the quantity U by means of the following expression:

$$U = \frac{f\times b\times\left(\alpha\times s + n\times b\times\frac{u}{c_1}\right)}{\left(2\alpha\times s + n\times b\times\frac{u}{c_1}\right)}$$

where we introduce the quantity f for the purpose of simplifying the calculation, which quantity represents the following expression:

$$f = \frac{\pi\left(1-\frac{\alpha_1}{90}\right)\frac{u}{c_1}}{\left(\cos\alpha_0-\frac{u}{c_1}\right)}$$

The quantity t is also dependent upon the dimensions of the blades, as we have approximately the following relation:—

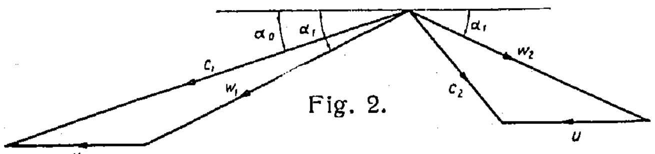
$$\frac{t\times\sin\alpha_1}{b} = Const. = C; \text{ or } t = \frac{b\times C}{\sin\alpha_1}$$

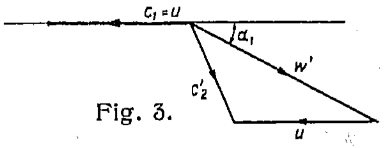
If we introduce these values in the above equation (3) for $\alpha\times s$, we can easily see that we have a quadratic equation for α. We obtain as possible solution of this equation the following expression which gives us:

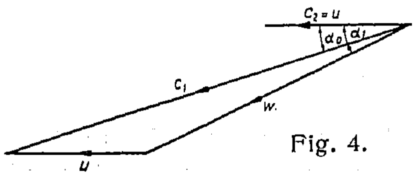
$$\alpha = \frac{b}{4B}\left[f+\frac{2C}{\sin\alpha_1}-m\frac{u}{c_1}+\sqrt{\left[m\frac{u}{c_1}-f-\frac{2C}{\sin\alpha_1}\right]^2+8m\frac{u}{c_1}\left[f+\frac{C}{\sin\alpha_1}\right]}\right]$$

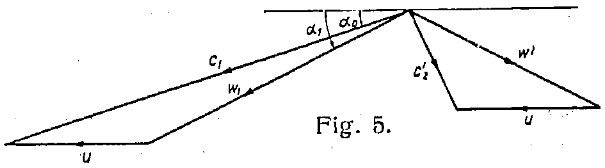
This enables us to determine the relative loss v_r by means of the equation (2).

We have plotted in Fig. 7 the relative loss v_r as a function of u/c_1 for various values of b/B in the case of an angle of guide blade of 15° and for $n = 0.8$. We see, from this example, that the relative loss v_r increases nearly in a rectilinear way


Fig. 2.


Fig. 3.


Fig. 4.


Fig. 5.

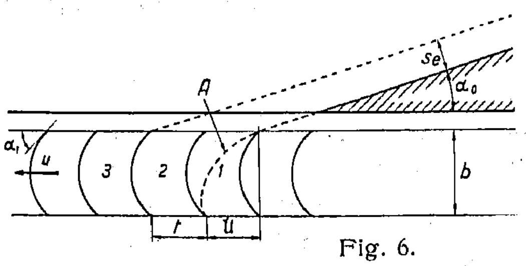


Fig. 6.

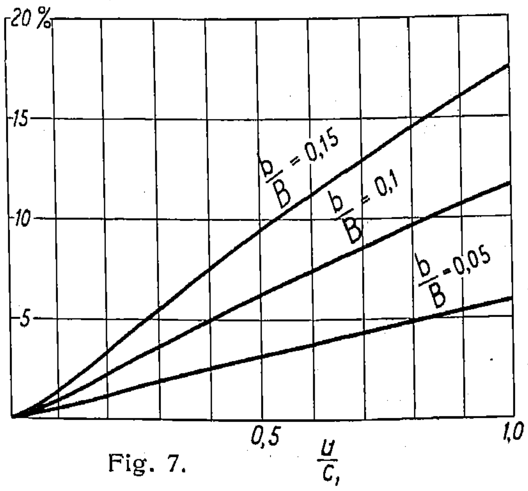


Fig. 7.

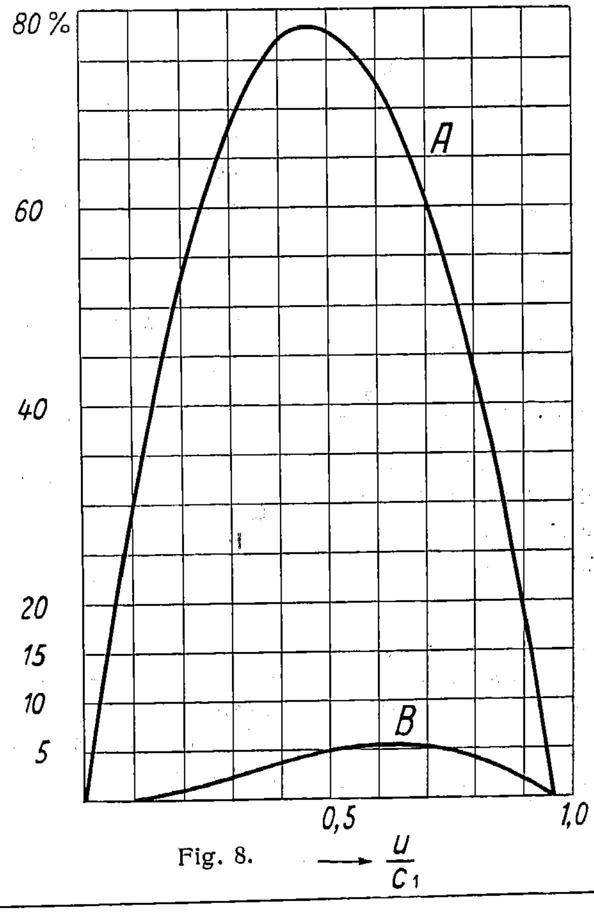


Fig. 8.

with u/c_1, that with a constant length of admission B, it varies in the same ratio as the axial width b of blades and that with a constant width b of blades, the variation is in inverse ratio to the length of admission B. It can be further seen that this relative loss can reach quite a high value in the case of large values of b/B.

The curves in Fig. 7 show how much of the useful power attainable at the periphery of the runner is lost, as a result of partial admission. When comparing the value of these losses with the energy available for work in the turbine, we have to take into account the efficiency at the periphery of runner. If, for instance, the efficiency at the periphery of runner is represented by the curve *A* in Fig. 8, we obtain as curve representing the losses due to partial admission, on the basis of Fig. 7, and for $\frac{b}{B} = 0.1$ for instance, the curve *B*.

It should be noted here that these curves, as well as the whole of the above calculations are based on the assumption that there is no further utilisation of the outlet velocity from the runner. On the other hand, it cannot be concluded from the results obtained, that partial admission, as a whole, always leads to larger losses than full admission, as there are other losses occurring in the case of both modes of admission which also vary, when passing from full admission to partial admission, and affect, in part, the final result in opposite direction.

Emergency Governors on Oerlikon Steam Turbines.

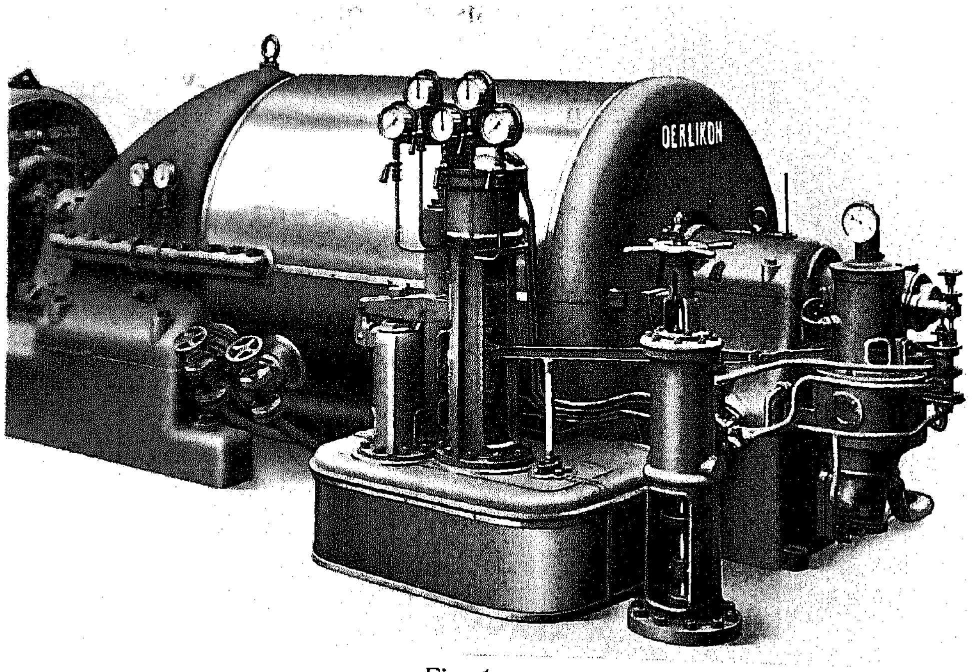


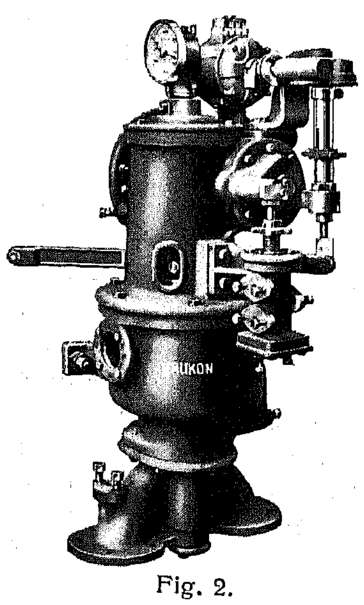
Fig. 1.

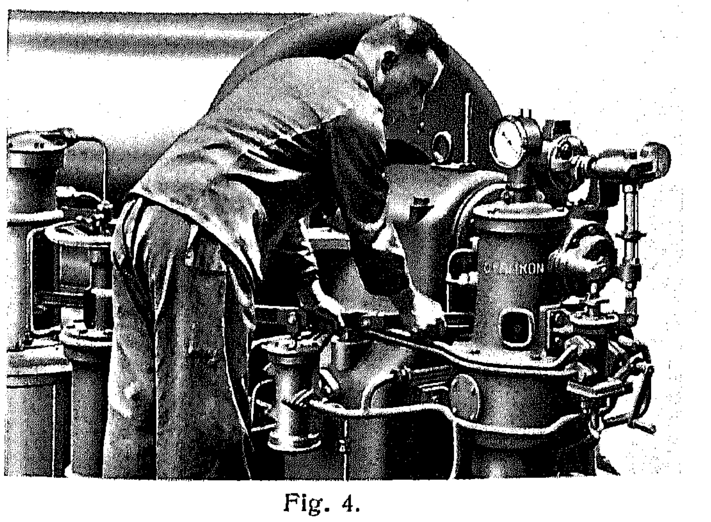
Of the many safety devices provided on Oerlikon steam turbines*) that for protecting the plant against racing is one of the most important. We propose to give below a brief description of the gear in question.

Fig. 1 represents an Oerlikon steam turbine with safety device against racing of machine, fitted at the extremity of the turbine on the high pressure side; the safety device itself is shown separately in Fig. 2. The main component part of this safety device is the centrifugal governor which is mounted, in most cases, directly on the turbine shaft. There are four types of governors of this description to meet the following conditions:—

1) In the case of small outputs and for a speed of 3000 RPM, good results have been obtained with a governor such as shown in Fig. 3. This governor is mounted directly on the turbine shaft and has, therefore, the same speed as the turbine shaft itself; it consists of an eccentric ring (1), a spring (2) and a guide pin (3). The eccentric ring, which acts as fly-weight, and the spring are so adjusted in relation to each other that, at about 10 to 15 % overspeed, the fly-weight overcomes the force of the spring and moves from the centre outwardly. The whole system is calculated astatically, that is to say, the increase in the centrifugal force as the fly-weight moves outwardly, with the machine running at constant speed, is exactly the same as the increase in the force exerted by the spring. It is, however, actually necessary to have a small increase in speed in order to bring the fly-weight from its initial position to its end position. The fly-weight (1), as it moves outwardly, comes into contact with a nose (4) and gives the latter an angular displacement about the axis (5), with

*) Oerlikon Periodical Communication No. 87.


Fig. 2.


Fig. 4.

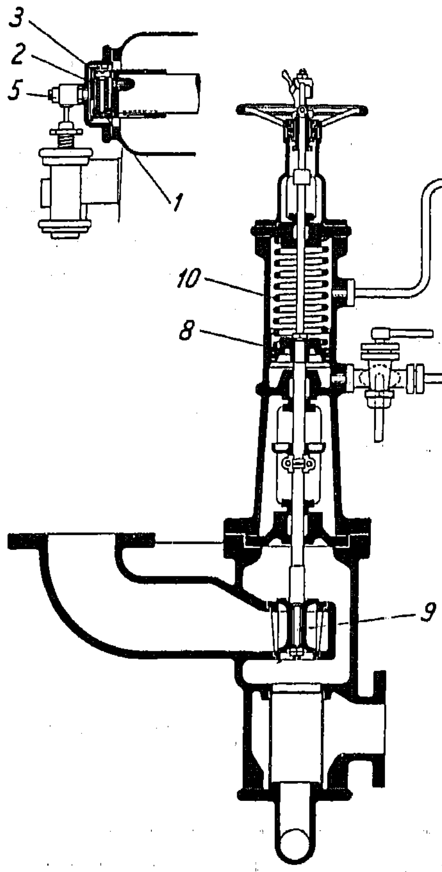


Fig. 3.

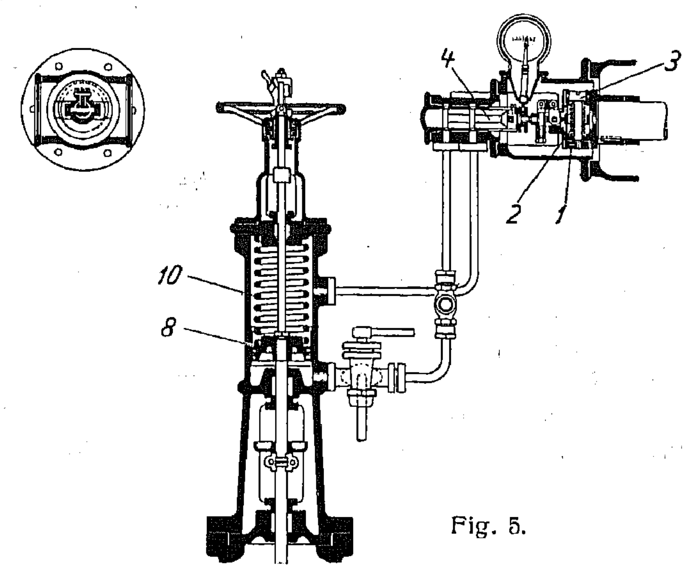


Fig. 5.

the result that the rod of the spring-loaded pilot valve (6) can slide into the opening (7). The pilot valve (6) is thus displaced and the oil pressure under the piston (8) can flow out. At the same time, oil under pressure penetrates above the piston (8); consequently, the main steam inlet valve (9) of the turbine closes through the action of the compressed spring (10) and also of the oil pressure. The turbine is, in this way, entirely closed down.

It may be mentioned that the force exerted by the compressed spring (10) itself is a multiple of the friction resistance of the gland. When, to this force is added the oil pressure above the piston (8), the available closing force, acting on the main steam inlet valve (9), amounts to more than 1000 Kgs, so that there is no danger of the valve (9) failing to close through the jamming of the gland. Experience has also shown that this gear works in all cases satisfactorily. This safety device is to be tested from time to time. This is done by holding down the governor bar with the hands, as shown in Fig. 4.

2) In the case of large outputs and for a speed of 3000 RPM, use is made of an emergency governor, such as represented in Fig. 5, which works, even at the normal speed of turbine. This governor too is mounted directly on the turbine shaft and has, therefore, the same speed as the turbine shaft itself. It consists also of an eccentric ring (1), a spring (2) and a guide pin (3); the eccentric ring (1) is linked up to the pilot valve (4) by means of lever gear. The spring (2) is calculated in such a way that the eccentric ring (1) starts to move with the pilot valve (4) even at normal speed. At about 12 to 15 % overspeed, the pilot valve switches over the oil under pressure, with the result that the steam inlet valve (9) of the turbine closes. As soon, however, as the speed of the turbine drops to normal, the main steam inlet valve opens again and enables the machine to run at normal speed. In this case, there is a closing force of several thousand Kgs. available for closing the main inlet valve (9), so that the valve closes without difficulty, even when, for instance, the machine has been in continuous service for months and although the spindle of the gland may be coated with scale.

3) In the case of large two and multi-cylinder turbines, two and more emergency governors are provided. A 50,000 KW. turbine at 3000 RPM with four cylinders, such as shown in Fig. 6 has, for instance, three emergency governors. The first emergency governor, which is on the high pressure

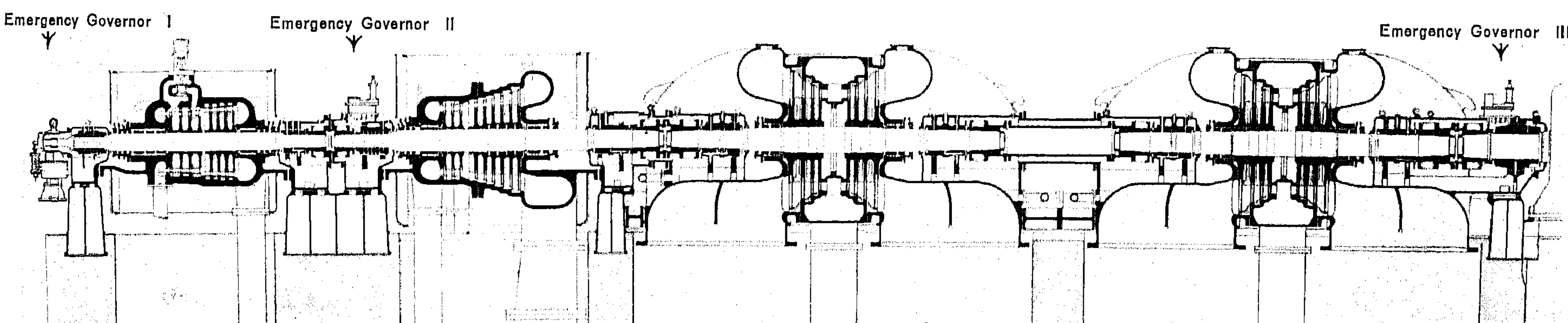


Fig. 6.

cylinder, is built exactly as in the case of 2) and is adjusted for about 10 % overspeed. The second and third safety governors are built as described under 1), but each emergency governor operates a steam valve of its own. As these emergency governors have each to be tested separately, from time to time, provision is made for variable gears, in the case of the second and third emergency governors, as shown in Fig. 7. In view of this, it is possible to cause the operation of these governors even at normal speed.

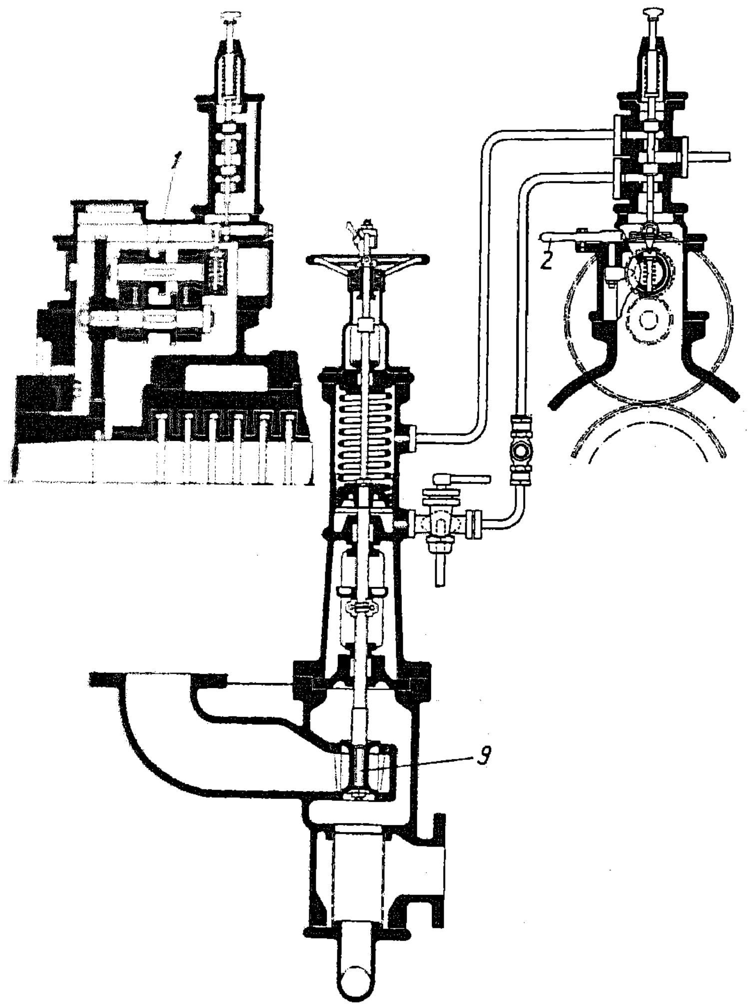


Fig. 7.

The procedure for testing the three emergency governors is as follows:—

The first emergency governor on the high-pressure cylinder is tested by holding down the governor bar as shown in Fig. 4; it should come into play at about 10 % overspeed. The second emergency governor on the middle pressure cylinder is tested by adjusting the variable gears (1) (Fig. 7) by means of the lever (2), for the higher ratio, so that the emergency governor revolves at 3400 RPM, when the turbine shaft is running at 3000 RPM. This governor closes down the turbine entirely at 3400 RPM. After testing the emergency governors, the variable gears are set again for the ratio 1 : 1, by means of the lever (2). The third emergency governor on the coupling side of the complete turbine is tested in exactly the same way as the second emergency governor; it is adjusted for 15 % overspeed.

4) In the case of small high speed machines, use is also made of emergency governors built directly on the turbine shaft, as shown in Fig. 8. The fly-weight is, in this case, merely in the shape of a segment of a circle. The governor works otherwise exactly as described under 1).

5) In the case of large high speed machines, the emergency governor is fitted on the low speed shaft of the main governor and of the oil pump. There is, in this case, no danger of the turbine racing in the event of a defect in the reduction gear, as a further safety device closes down the whole plant in the event of failure of the oil pump, which also works off the spindle of the main governor. In the case of this emergency governor, too, we have (Fig. 9) an eccentric ring (1) with spring (2) and guide bolt (3). This governor is calculated exactly as that described under 1).

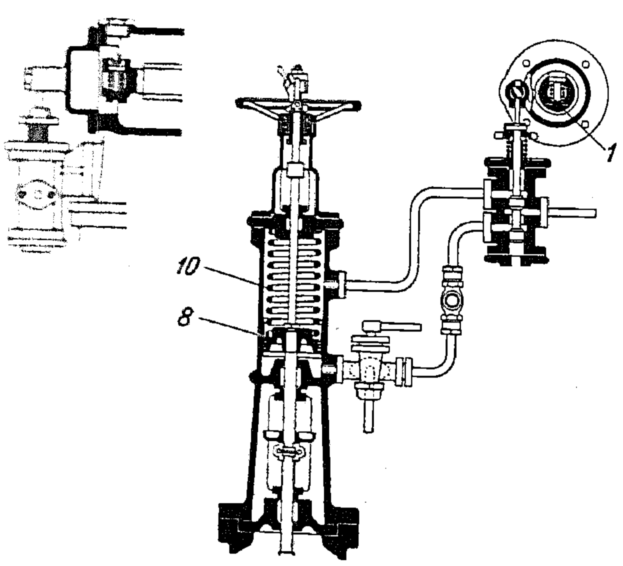


Fig. 8.

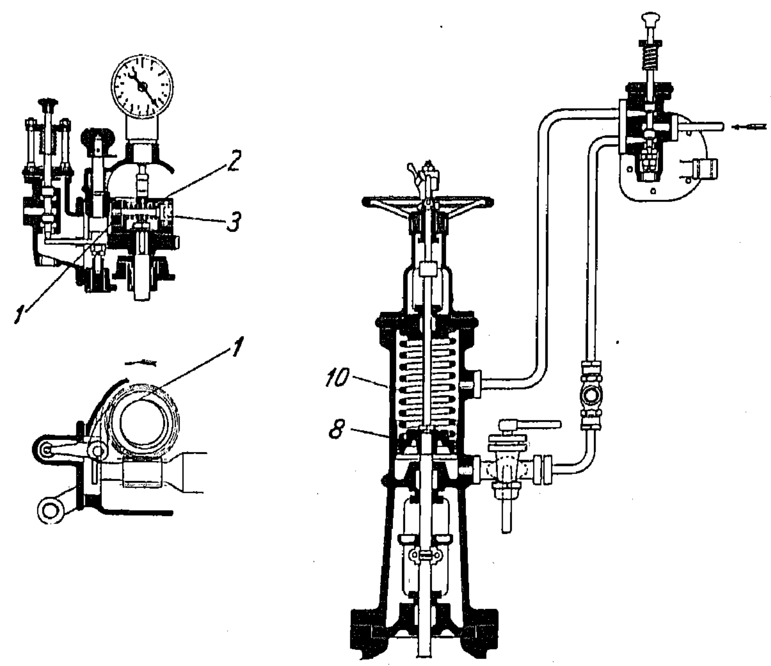


Fig. 9.

BULLETIN OERLIKON

No. 120 — June 1931

Regenerative Braking on Single-phase Railways.

Ever since the introduction of electric traction the property of motors of electric vehicles of being able, under certain conditions, to work as generators has been utilised for electric braking when travelling downgrade and when bringing the trains to a standstill. At the outset, this property was mainly made use of in the case of D. C. tramways where it was possible to alter in a relatively simple manner the connections for the purpose of braking, by causing the current generated by the motor to be absorbed by resistances or, in other words, to be converted into heat. The braking equipment was simplified in that the same resistances could be utilised as for starting up during traction service. This mode of braking, which was supplemented later on by the addition of electromagnetic rail brakes and solenoid brakes deriving, in certain cases, their current from the contact wire, is still used at the present day. The advantages secured by the provision of electric braking, resided in the fact that there was in addition to the mechanical brake, a further brake independent of the latter while, on the other hand, the wear of the wheel tyres and brake blocks was reduced.

When the electrification of standard gauge railways was taken in hand, the first idea that presented itself was to utilise also the advantages derived from electric braking as these were still more pronounced here in view of the long inclines and of the great speeds and braking forces. It was, on the other hand, an attractive proposition to convert into electric current, in the motors, the energy developed by the train when running down-grade and thus reduce the power to be supplied by the generating station instead of having to waste energy in resistances as in the case of resistance braking. It was also possible with regenerative braking to deal with greater train weights — up to the total train weight which the same locomotive can haul up-grade — than with resistance braking, as, when large braking forces have to be developed, the weight of the resistances and the space required for them is so great that it makes the task of accommodating these resistances in the locomotive very difficult and, if this can actually be done, renders the locomotive heavy and high in price. Regenerative braking presents special advantages over resistance braking in the particular case where, on the same mountain section, one train runs up-grade while another travels down-grade, as the energy developed by the first train can be used for feeding the second train, without its having to pass through the neighbouring substation and the connecting lines, thus reducing the pressure drop.

A further fundamental difference between resistance braking and regenerative braking resides in the fact that resistance braking is independent of the supply system and can, consequently, operate, even when the contact wire is not under pressure or when the current collector is lowered, while regenerative braking is only operative as long as the circuit locomotive — contact wire — substation or power station — track — locomotive is closed, and its action ceases when the circuit is interrupted by a switch on the locomotive or in the power station, or by a fault in the contact wire or in the current collector.

This „dependence upon the contact wire" has occasionally been put forward as an objection to regenerative braking, but quite wrongly. First of all, even in the case of a mode of braking independent of the contact wire, such as resistance braking, the braking circuit is liable to interruption as a result of a defect in the motor, or in the resistances or gear in the braking circuit, so that the braking effect suddenly ceases; secondly, electric braking can be combined, without difficulty, with mechanical braking in the case of regenerative braking too, as shown by experience in the case of locomotives actually built, in such a way that, in the event of an interruption of the braking circuit, the mechanical brake comes immediately into operation automatically and the racing of train is effectively prevented.

Regenerative braking has been applied to all current systems such as used for the operation of trunk line railways (direct current, three-phase and single-phase current). The problem was easiest to solve in the case of three-phase current as three-phase motors begin to generate automatically when their speed rises above synchronous speed. In the case of direct current and of single-phase current, it was more difficult to find a solution satisfying the requirements of railway service. It would lead us too far to draw a comparison here between the two current systems, with regard to the advantages presented by regenerative braking. We shall merely state as a fact that in both cases regenerative braking has passed the experimental stage and has been introduced for years and used in a great number of cases on D. C. and single-phase railways where it has proved a thoroughly reliable mode of braking.

We propose to deal here with regenerative braking on single-phase railways as, up to now, only relatively little

has been published regarding the practical results obtained[1]) and we shall confine ourselves in this connection to the Oerlikon system which is the system that has been applied in by far the greater number of cases [2]).

When the Swiss Federal Railways proceeded to electrify their lines with single-phase current and applied this traction system for the first time to heavy traffic on a large scale, the Oerlikon Company were able to put forward a suitable regenerative braking system in view of the investigations and tests they had carried out from an early date and the success they had achieved in this direction. The task the Oerlikon Company had set themselves was to evolve the simplest arrangement and one requiring as little attendance as possible, to limit the weight and space required by the braking equipment as far as practicable and, at the same time, to ensure that the power factor is not reduced more than permissible for the service.

The first description of this regenerative braking method[3]) appeared in the „Bulletin" of the Swiss Electro-Technical Association of October 1918; it was by Dr. H. Behn-Eschenburg, the then Managing Director of the Oerlikon Company and contained particulars of the equipment which the Oerlikon Company had fitted on one of the trial locomotives supplied by them to the Swiss Federal Railways. As the method described there has proved so satisfactory that it is still resorted to, even at the present day, without modification, we propose to quote some of the main points from this first publication and to give, in first place, the fundamental diagram of connections (Fig. 1). For this mode of braking, no further

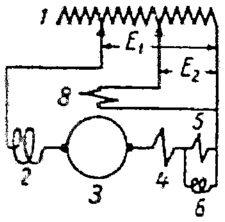
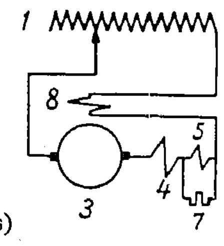


Fig. 1. Simplified diagram of connections for the Oerlikon system of regenerative braking for single-phase railways (on the right — traction, on the left — braking).



Key
(see also the following diagrams)

1 Transformer
2 Choking coil for braking
3 Motor armature
4 Motor compensating winding
5 Motor interpole winding.
6 Inductive interpole shunt
7 Ohmic interpole shunt
8 Motor field winding
E_1 Pressure of the armature circuit
E_2 Pressure of the excitation circuit

switchgear is required than the step switches or contactors provided for normal traction service; a choking coil of usual design is the only apparatus which is added to the standard motor equipment. The ordinary series motor is converted, with this arrangement, into a particular type of generator or motor which has new properties specially suited for braking, while the range of regeneration is extended for all loads over the whole speed range down to standstill (a result which is not possible with resistance braking), as with constant supply pressures, E_1 and E_2, the torque is constant at all speeds, down to standstill. The output increases in the same ratio as the speed. There is no danger of self-excitation or lack of stability. The reactance of the choking coil 2 is chosen in such a way that, together with the self-induction of the armature, of the interpole winding and of the compensating winding, it limits the armature current to a permissible value. There is, in place of the non-inductive shunt resistance connected in parallel with the interpole winding during traction service, an inductive shunt resistance for commutation purposes during braking.

This arrangement was given preference over the methods of excitation of the main field winding by special alternating current exciters or by connecting the main field winding to the armature circuit through current transformers, because the first of these methods leads to a great complication of the equipment and the second gives rise to difficulties in connection with the suppression of self-excitation with a frequency different from that of system.

The putting into operation of regenerative braking is extremely simple. As the connections for braking are made by the reverser, the driver of the locomotive has only to set the step switch in the zero position when coming to an incline, to shift the reverser into the braking position, and to shift the step switch upwards, until the desired braking effect is obtained. This operation can be carried out, no matter what the speed is when braking is applied, and requires very little time, so that there is no danger of an excessive acceleration of the train travelling down-grade before regenerative braking starts to act.

Tests were carried out with this first regenerative braking equipment in June 1919, after putting the locomotive into service on the northern section of the Loetschberg line which includes long inclines of 1 in 37. The locomotive was of the 1 B B 1 type, designed for hauling a trailing weight of 300 tons on gradients of 1 in 38.4 at a speed of 31 mph., the maximum speed being 46.5 mph. We find, in first place, from the account given of the trial runs by Dr. Behn-Eschenburg in the Schweiz. Bauzeitung of the 16th August 1919, that even the first practical tests showed the exceptional suitability, reliability and simplicity of this braking method. A run was made up-grade and down-grade on the same section, owing to its suitability for obtaining a constant speed, first with the locomotive alone and after with a train coupled to it, having a weight of 197 tons, the ascent, the speed and all the most important electrical quantities being determined. During these trials, however, the instruments used were not precision instruments but the measuring instruments of the locomotive which were less correct in their readings. The results agreed, nevertheless, relatively well. The following are some of the figures obtained: The efficiencv of the conversion of electric and mechanical energy, including the electric losses on the locomotive, (the power taken by the auxiliary services being 30 KW) was, for up-grade operation, with a tractive effort of about 22,000 lbs, and a speed of about 31 mph, about 83 %, and for down-grade operation, with a corresponding liberated tractive effort of 14,500 lbs. on an incline of 1 in 37, with the train travelling at 38.5 mph, about 75 %. Both figures refer to the high tension side. The power factor, also measured at the contact wire, was for the up-grade run about 0.9 and for the down-grade run about 0.53. The means by which the latter value of power factor could be further improved was also pointed out. It must, however, be borne in mind that the disadvantage of having a power factor, which is considerably lower than during traction service, is in practice a matter of relatively little importance in the case of a large railway system, where the number of trains

[1]) See, for instance, Wechmann „Der elektrische Zugbetrieb der Deutschen Reichsbahn", 1924.

[2]) The Oerlikon Company have also supplied numerous D. C. locomotives equipped for regenerative braking, to the P. L. M. Railway and to the Spanish Northern Railway, in particular. The conditions laid down with regard to regenerative braking were, in the first case, locomotive weight + 300 tons, speed to be limited to 22 to 25 mph. on inclines of 1 in 33.3 and, in the second case, braking force at rim of driving wheels 11600 to 18700 lbs at 11 to 37 mph.

[3]) The same paper appeared in the issue of 2nd Nov. 1918 of the „Génie Civil".

on inclines suitable for electric braking is relatively small in comparison with the number of trains running with a high power factor. This is the case for the Swiss Federal Railways and the latter use exclusively the Oerlikon braking system for all their locomotives equipped for regenerative braking. The weight of the additional equipment required for regenerative braking amounts to about 7% of the weight of the whole electrical equipment; it represents 3½% of the locomotive weight and 1% of the whole train weight. This increase in weight is very small when compared with the very great advantages obtained with it.

Before we deal with the further locomotives of the Swiss Federal Railways equipped for regenerative braking, mention can be made of two contracts placed by other railway companies which are interesting in that it was a question of fitting regenerative braking equipments in locomotives already completed and in service. The problem was here rendered more difficult than would have been the case for new locomotives owing to the fact that the braking equipment had to be adapted to the existing electrical and magnetic conditions of the motor and transformers and to the existing mode of connection.[4])

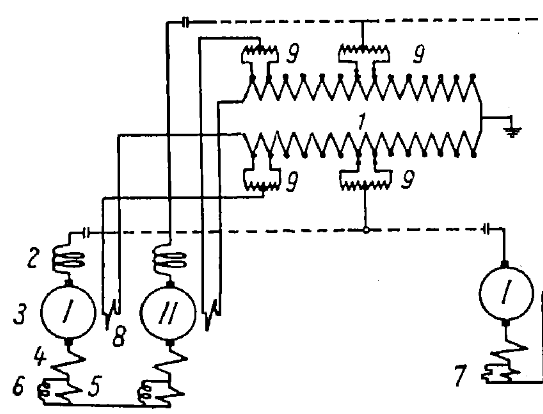


Fig. 2. Diagram of connections of the Loetschberg locomotive.
(1 to 8 for key see Fig. 1; 9 Bridging coils)

The Loetschberg Railway Company (B. L. S.) had a regenerative braking equipment fitted on one of their locomotives, type 1 E 1, built in 1913; these locomotives serve for hauling trains with a weight of 310 tons at a speed of 31 mph on the gradients of 1 in 37 of the Loetschberg line. The object of the regenerative braking equipment was mainly to provide an additional brake independent of the mechanical brake. The braking equipment was designed for dealing with a train weight of 250 tons (including the locomotive weight of 106 tons) on inclines of 1 in 37. The connections for traction and braking are shown in Fig. 2. As will be seen, the two driving motors are arranged in series with the L. T. windings of the two steptransformers during traction, and this mode of connection was thus also indicated for the armature circuit of the motors during braking. The excitation windings are connected to additional switches in order to be able to adjust the excitation pressure for the most favourable value, independently of the pressure in the armature circuit. Fig. 3 gives the profile of the section Spiez-Kandersteg, over which the trials were carried out. Fig. 4 shows the power taken during the up-grade run in the case of two different train weights, the curves being based upon the readings of the recording wattmeter in the H. T. circuit of the locomotive.

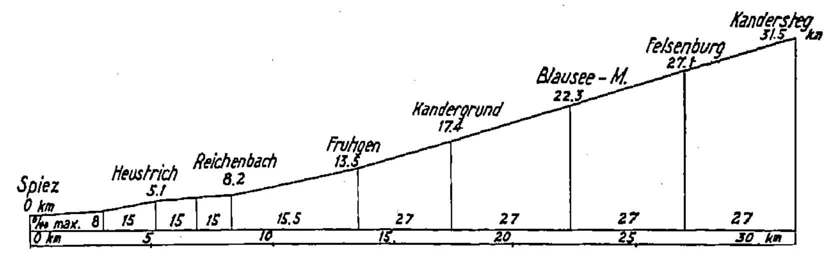


Fig. 3. Profile of the Kandersteg-Spiez section.

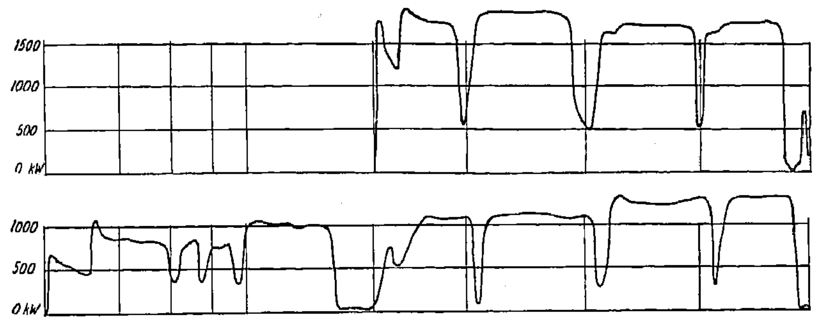


Fig. 4. Traction. Trains of 261 and 222 tons.

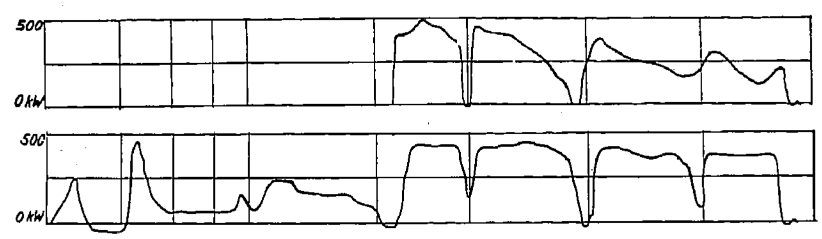


Fig. 5. Regenerative braking. Trains of 261 and 222 tons.

Fig. 5 gives the output during the down-grade run for two trains with the same weight, the curves being based upon the readings of the same instruments. Calculations showed that 20 to 30% of the energy taken for the up-grade run was fed back into the system during the down-grade run with regenerative braking; a further fact to be taken into account is that the power consumed by the auxiliaries of the locomotive during the up-grade run is included in the energy taken by the locomotive, while it is not included in the energy fed back into the system by the locomotive. The power factor in the H. T. circuit was about 0.5. Such quantities are difficult to determine accurately for the mere reason that it is almost impossible, during actual service, to obtain a state of equilibrium throughout the duration of measurements on a mountain section with numerous curves, while the pressure at contact wire is liable to fluctuate and, consequently, the braking force too.

The Rhaetian Railway Co. (Rh. B.) has, since 1914, three 800 HP. Oerlikon locomotives of the 1 D 1 type in operation on its metre gauge line. When the construction of the Praettigau line, which links up Landquart, Klosters and Davos, and includes gradients up to 1 in 22.2 of considerable length, was taken in hand in 1920, the Rhaetian Railway Co. thought it necessary to provide, in addition to the vacuum brake, an electric brake, and ordered from the Oerlikon Company the regenerative braking equipments for the three locomotives in question, which lent themselves to the purpose, both in the matter of space and weight. The conditions laid down were that the equipments in question were to be capable of limiting the speed of the trains to 18.6 mph, without the assistance of the vacuum brake, the train weights (including a locomotive weight of 59 tons) and the gradients being as follows: 80 tons on a gradient of 1 in 2.22, 100 tons

[4]) Oerlikon Bulletin No. 23, May 1923.

on a gradient of 1 in 28.6, or 120 tons on a gradient of 1 in 40. We give here, as in the case of the Loetschberg locomotives, the diagram of connections for traction (Fig. 6, right side) and for braking (Fig. 6, left side), as well as the profile of the Landquart-Davos line (Fig. 7) and the curves showing the power taken by the locomotive during up-grade operation (Fig. 8) and that fed back into the system during down-grade operation (Fig. 9).

The trial runs, which were carried out with a total train weight of 84 tons, took place at night, as there were then no other trains on the line and only the Kublis power station was in operation, so that both the power taken during the up-grade runs and the power recovered during the down-grade runs could be measured there. In his report on these trial runs [1] the Chief Electrical Engineer of the Rhaetian Railway Co., Mr. W. Duerler, stated that the electric braking

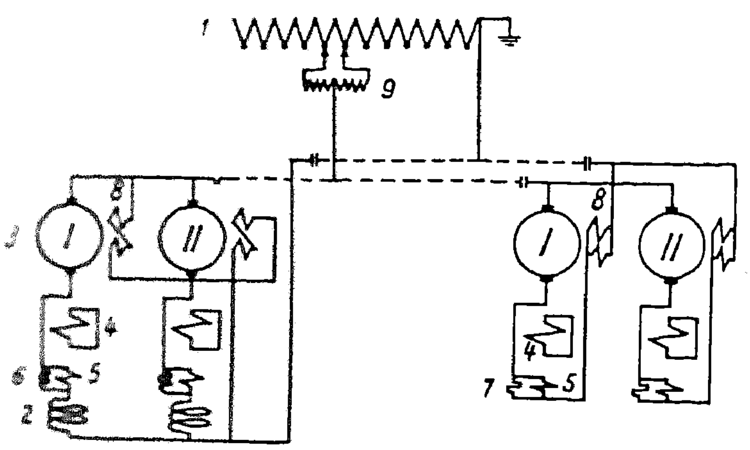


Fig. 6. Diagram of connections of the locomotive of the Rhaetian Railway. (For key see Fig. 2)

acted without any trouble and very smoothly and that it was easily possible to limit the speed to the desired values, with the train weights prescribed, and to bring the train to a standstill. He reckons that during the down-grade operation on gradients of 1 in 28.6 to 1 in 22.2 about 30 % of the energy taken during up-grade operation was returned to the supply system, at a power factor of 0.3 to 0.4. At the same time, he points out that there is a relatively large amount of opwer, when compared with the output of motors, namely 42 KW, taken for auxiliary services, such as heating of train (the trials took place in winter), supply of compressor and vacuum pump, and that during the warm season, when no heating is necessary and the power component of the current led back into the system is correspondingly larger, the values of power factor would be higher than obtained at the trials. The power recovered during the down-grade run over the whole line, Landquart-Davos-Landquart, which includes long sections with small gradients, amounted to about 12 % of the energy taken during up-grade operation. Mr. Duerler has calculated that, under these conditions, when the locomotives are fully utilised, the installation cost of the regenerative braking equipment could be paid off by the saving of energy alone, although the order was placed when prices were high. In addition to this, there is the saving in brake blocks and wheel tyres. On the other hand, it must be borne in mind that provision had to be made anyhow for electric braking and consequently the only factor that has to be considered is the higher cost as compared with resistance braking.

[1] Schweizerische Bauzeitung of 20th May 1922.

We pointed out earlier in this article that the fact of having a low power factor did not constitute a serious draw-back for a large railway system. This is confirmed by the report of Mr. Duerler insofar as he says that, although a low power factor is not desirable for the generating station, all the more so as the Rhaetian Railway Company had to guarantee in their contract with the power supply company that the power factor of load was not to drop below .7, the fact that the series motors work with a considerably better power factor when normally loaded, ensures a sufficient margin.

The additional gear required for regenerative braking represents a weight amounting to about 9 % of the weight of the whole electrical equipment, or a little more than 4 % of the weight of the locomotive and approximately 3 % of

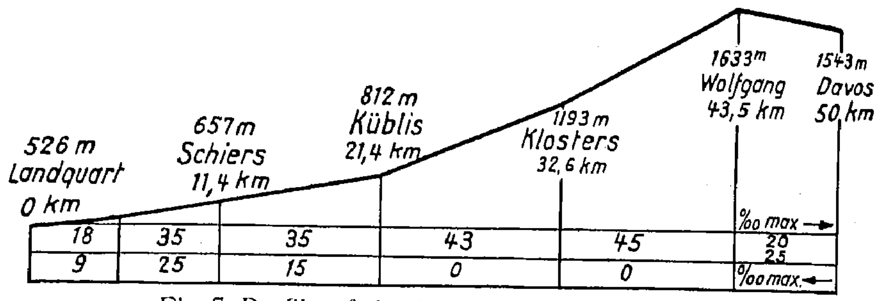


Fig. 7. Profile of the Landquart-Davos section.

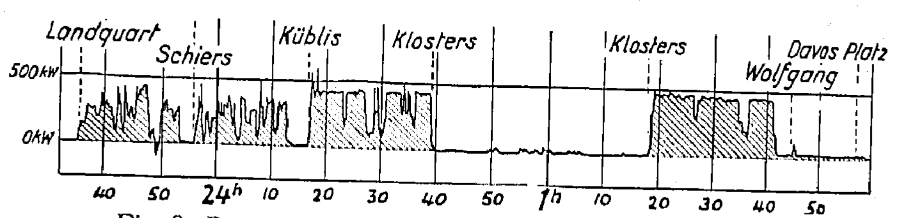


Fig. 8. Power consumption curve during up-grade run.

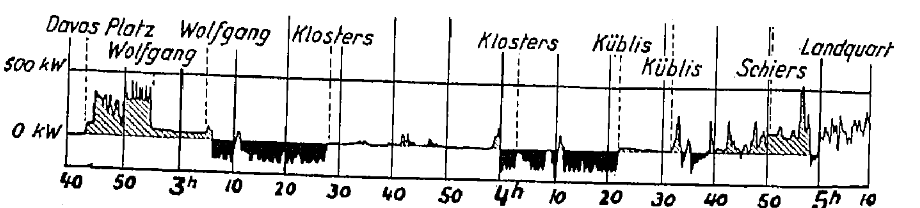


Fig. 9. Output curve during down-grade run.

the weight of the whole train. The fact that these figures are higher than those given previously for the locomotive 1 BB 1 of the Swiss Federal Railways is easy to understand, as the gradients are steeper and the locomotive of the Rhaetian Railway is less powerful, and its weight is only half that of the locomotive of the Swiss Federal Railways.

We propose to deal briefly with the differences in constructional details between the regenerative braking equipment of the Loetschberg (B. L. S.) locomotive and that of the locomotive of the Rhaetian Railway (Rh. B). In the case of the Rh. B. locomotive, it was possible to divide the main field winding into two halves, which were connected, as previously, in parallel for traction, but in series for braking. In view of this, the field winding could be fed from the same transformer tapping as the armature circuit, as can be seen from Fig. 6 (left side), so that the excitation pressure varied for each change of tapping in the same ratio as the pressure applied to the armature circuit. This does not mean in any way a departure from the fundamental arrangement for braking, namely the conversion of the motor into a shunt machine and the introduction of a choking coil in the rotor circuit.

In the case of the B. L. S. locomotive the conditions were less favourable, for which reason armature circuit and excitation circuit were connected separately to the transformer. The results, as far as braking is concerned, were up to expectations, both in the case of the B. L. S. and of the Rh. B. locomotive. It was, however, found, after the B. L. S. locomotive had been in operation for some time and electric braking had been regularly used, that the power required of the motors for up-grade operation alone was so very near the limit of their capacity, that it was necessary to let them run without current when travelling down-grade in order that they might cool down, and that they would be subjected to excessive stress if they had also to generate current during the down-grade run. This would, of course, also be the case if resistance braking was used instead of regenerative braking, to the same extent, and must be expected when a motor which is already fully loaded without electric braking, has in addition, to serve for any kind of electric braking. For this reason, the Loetschberg Railway Co. was compelled to abandon the idea of introducing electric braking on all their 13 locomotives of the 1 E 1 type. In the case of the Rhaetian Railway, however, the conditions in this respect were more favourable and regenerative braking has been used there ever since with the best results.

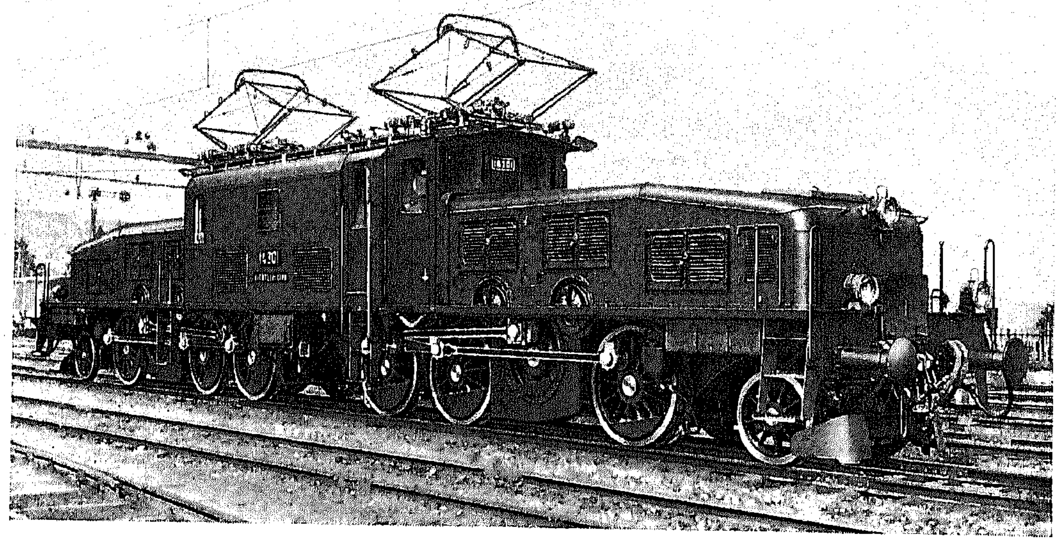


Fig. 10. 1 C C 1 freight locomotive of the Swiss Federal Railways.

In the meantime, the electrification of the Swiss Federal Railways had made rapid progress. The first contract placed with the Oerlikon Company was for 33 locomotives of the 1 CC 1 type for hauling the freight trains on the St. Gotthard line. These locomotives have a $1^1/_2$ hour rating of 2200 HP. at a speed of 21.7 mph and a weight of 129 tons; they have to haul freight trains representing a trailing weight of 430 tons up the gradients of 1 in 38.5 of the St. Gotthard line at a speed of 21.7 mph. These locomotives are all equipped for regenerative braking and it was stipulated that this mode of braking should be capable of dealing with the weight of the locomotive. The braking equipment was, however, so dimensioned as to permit of its use for dealing with the whole train too. Up to the present, this has not been done by the Swiss Federal Railways for working reasons. The locomotives in question are locomotives Nos. 14251-14283. The weight of the additional equipment required for regenerative braking represents 3 to 4% of the weight of the locomotives. The value of power factor is comprised between 0.5 and 0.6 for the total load including the power taken by the auxiliaries of the locomotive.

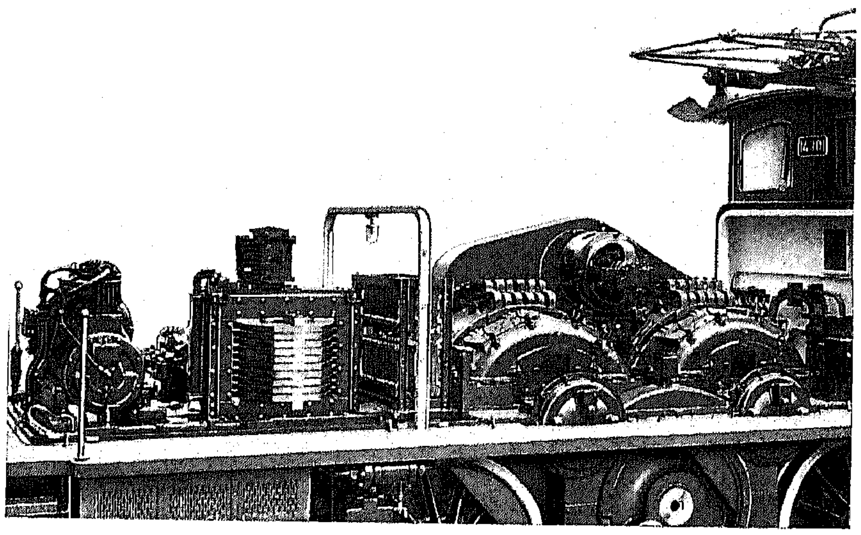


Fig. 11. Bogie of a 1 C C 1 locomotive of the Swiss Federal Railways, uncovered.

A subsequent order was placed for 18 locomotives of the same type 1 C C 1 but with a considerably higher capacity. The locomotives in question are locomotives Nos. 14301-14318 (Fig. 10). In place of the conditions laid down for the earlier series of locomotives, namely, trailing weight of 430 tons, to be hauled on gradients of 1 in 38.5 at 21.7 mph, the following was stipulated: Train of 1400 tons to be hauled at 21.7 mph. on gradients of 1 in 100, at 27.9 mph

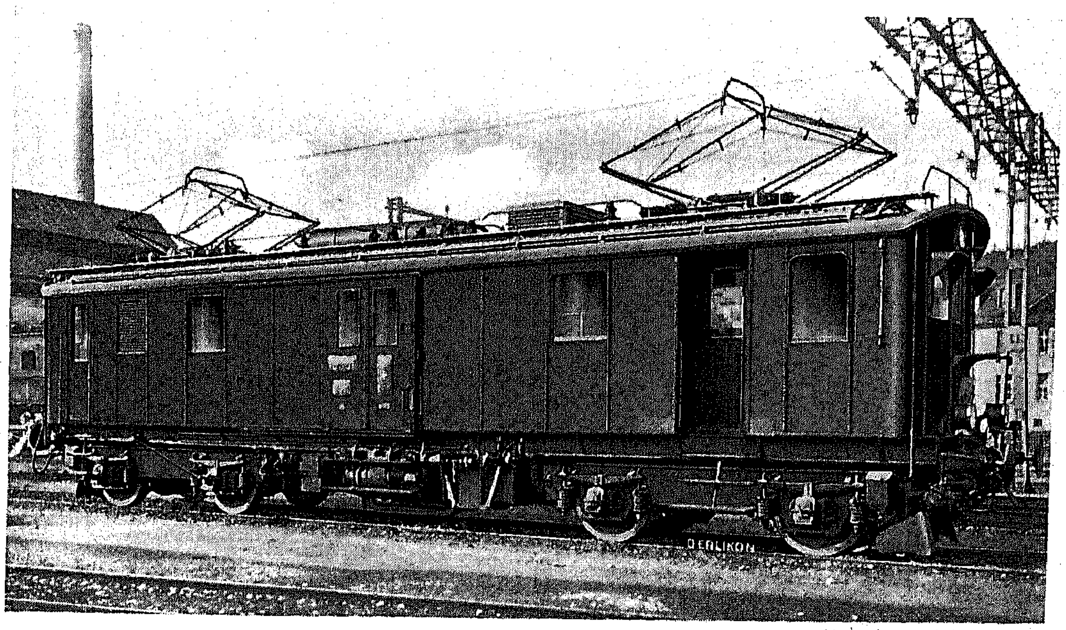


Fig. 12. Single-phase motor coach of the Swiss Federal Railways equipped for regenerative braking.

on gradients of 1 in 200, at 34.1 mph on gradients of 1 in 300 and at 40.3 on level track. The one-hour rating of these locomotives is 2720 HP. at 20.5 mph and their weight is 131 tons. These locomotives too are equipped for regenerative braking. The connections of the motor circuit are shown in Fig. 13 right side in the case of traction and in Fig. 13 left side in the case of braking. The additional equipment required for braking is represented in Fig. 11.

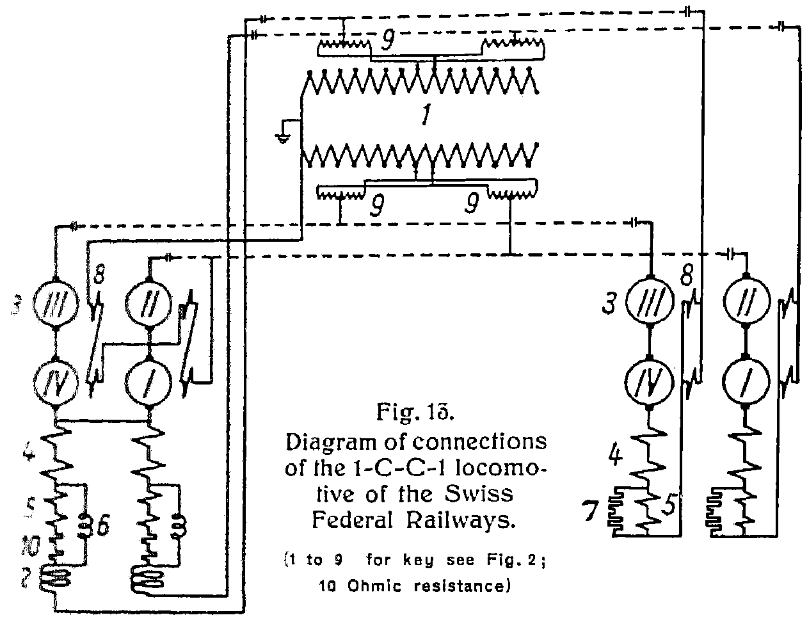


Fig. 13.
Diagram of connections of the 1-C-C-1 locomotive of the Swiss Federal Railways.
(1 to 9 for key see Fig. 2; 10 Ohmic resistance)

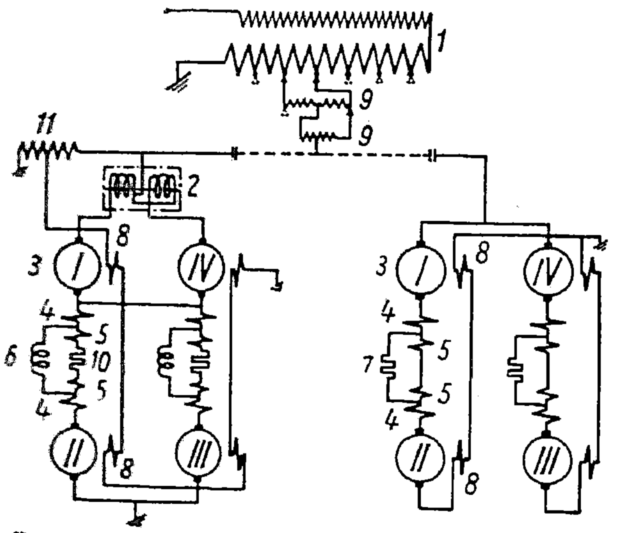


Fig. 14. Diagram of connections of the motor coach of the Swiss Federal Railways.
(1 to 10 for key see Fig. 13; 11 Transformer for braking excitation)

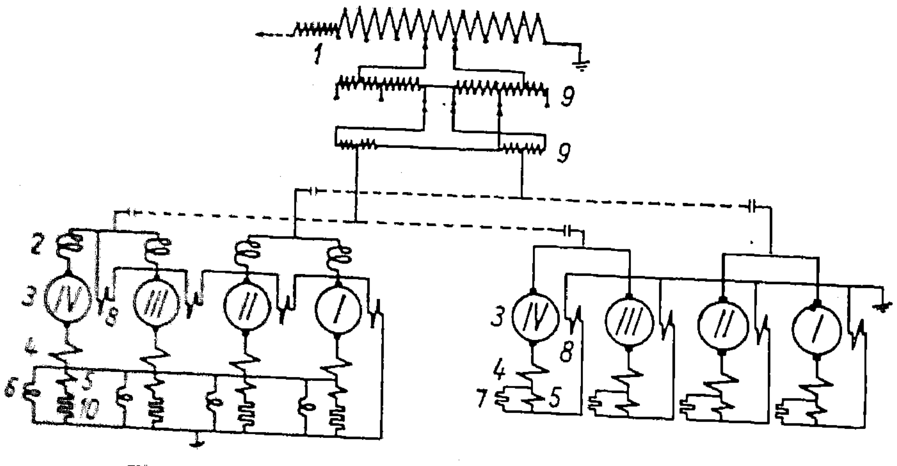


Fig. 15. Diagram of connections of the 2Do1 locomotive of the Swiss Federal Railways.
(For key see Fig. 13)

The choking coil for braking can be seen between the compressor and the nearest driving motor, as well as the two small resistances which serve to ensure good commutation.

Regenerative braking is, however, not only suitable for heavy locomotives but also, in certain cases, for motor coaches. This has proved to be the case for the motor coach No. 18561 (Fig. 12) supplied by the Oerlikon Company to the Swiss Federal Railways in 1930. This motor coach, which is intended for passenger trains, is fitted with motors with a one hour rating of 1340 HP and designed for a speed of 30 mph. Owing to the fact that it was laid down that this motor coach was to be capable of working with multiple control in conjunction with existing motor coaches, built by another firm, the Oerlikon Company did not have a free hand for designing the control. In spite of this, they were not only successful in fulfilling the latter condition, but were also able to provide a regenerative braking equipment generally in accordance with the design (Fig. 14) they have evolved with such satisfactory results in practice, which in this case has been specially adapted as regards control to the usual arrangement of motor coaches. In view of the numerous stops following each other very rapidly, and the short distance over which the trains had to be brought to a standstill, it would not have been possible for the driver to shift the controller each time to the zero position, then to set the reverser in the braking position and move the controller once more to the suitable notch, while at the same time operating the compressed air brake — the exclusive use of electric braking for the train is impossible under the conditions in question. The operations to be carried out by the driver were, therefore, simplified in the following way: — When approaching a stopping place, the driver brings the controller to the zero position, then presses a button in the crank handle which causes the changing over of the reverser from the „forward" to the „braking" position. As soon as the position of reverser is changed over, the driver can move the handle of controller forward and in this way apply the corresponding pressure to the armature and field. With this braking arrangement, it is possible to deal with a total train weight of 140 tons on gradients of 1 in 40 for an hour.

When, a little time ago, the Emmenbruecke-Wildegg-Beinwil-Muenster section of the former Seetal railway, acquired by the Swiss Federal Railways, was converted to their traction system (15000 volts, $16^2/_3$ cycles), the 8 motor coaches to be used on that line were equipped for electric braking, on account of the relatively heavy gradients. In view of the excellent results obtained with the regenerative braking equipment on the motor coach No. 18561, the Swiss Federal Railways placed an order with the Oerlikon Company for the gear required for regenerative braking to be fitted on 8 luggage motor coaches Nos. 18501—18508. As the existing electrical equipment of these motor coaches had not been supplied by the Oerlikon Company and did not, therefore, correspond to that of the motor coach No. 18561, it was unfortunately not possible to use the same material for the braking equipment. The gear provided, proved, however, so well adapted to the existing motors and transformers that even at the first trial run, braking took place without any trouble and all requirements could be fully complied with. We are not reproducing here the diagram of connections, as it does not differ essentially from that of the motor coach No. 18561.

When the Swiss Federal Railways took over the service of the Italian section — Iselle to Domodossola — of the Simplon line, converted to the single-phase system, and including long gradients of 1 in 37, and ran the trains with their own locomotives, they found it necessary to equip the locomotives intended for this line for regenerative braking, as otherwise the pilot locomotives could only have run at a very limited speed on the return downgrade journey to Domodossola, in order to comply with the existing safety regulations, or a brake van would have had to be coupled to them. Both these precautions became unnecessary with locomotives equipped for electric braking, and the Swiss Federal Railways requested the locomotive builders to examine whether an electric regenerative braking equipment could be fitted on the 2 D_0 1 locomotives (Fig. 19) of their standard express type with 4 motors and individual drive, in the course of construction and, if so, to submit proposals. The proposal put forward by the Oerlikon Company proved to be the most satisfactory, so that this firm secured the contract for equipping, in first place, ten such locomotives, for regenerative braking. The order was subsequently extended to 30 locomotives in all. The braking equipment was to be dimensioned in such a way as to be capable of dealing with the locomotive weight of 120 tons on a gradient of 1 in 37 during the downgrade runs and of limiting the speed to 40.3 mph. Overloading for short periods is, of course, permissible, as in the cases previously mentioned, and braking can be applied right down to standstill.

It will be readily unterstood that it was no easy matter to accommodate in a correct and appropriate manner, on a locomotive of which the design had been fixed in every detail and where the axial pressure amounted very nearly to the maximum permissible value of 20 tons, the necessary parts such as choking coils and inductive shunts for the interpoles and the larger reversers now performing the further function of making the braking connections. This was done by subdividing the braking equipment and mounting on each motor the parts belonging to it (Fig. 20). This entailed, it is true, an increase in the total weight of the braking equipment but ensured, on the other hand, a uniform distribution of the weight over the four driving axles, so that it was possible to keep within the permissible value of axial pressure. The diagram of connections for traction and for braking is given in Fig. 15.

A 2 $D_0$1-locomotive weighs 118.5 tons without the braking equipment and the same locomotive fitted with regenerative braking equipment has a weight of 123 tons. The extra weight resulting from the braking equipment thus amounts to 4.5 tons, which represents 3.5 % of the weight of the locomotive, or 7.5 % of the weight of the electrical equipment of the latter.

We have finally to deal with the latest locomotives of the Swiss Federal Railways - the two **large St. Gothard locomotives** of the 1 B_0 1 B_0 1 + 1 B_0 1 B_0 1 type, ordered at the beginning of 1930 and now in the course of construction. The electrical equipment of one of these locomotives, No. 11801, is being supplied by Messrs. Brown Boveri & Co. and that of the other, No. 11851, by the Oerlikon Co. The two locomotives are being equipped for regenerative braking for dealing with the locomotive weight of 230 to 240 tons. The system adopted is that of the Oerlikon Company who are supplying the equipments for both locomotives. Electric braking is to be used exclusively, on gradients of 1 in 37. The one-hour rating is 6640 HP. in the case of locomotive No. 11801 and 7200 HP. for No. 11851. The locomotives are intended for hauling the heaviest express and freight trains up the steep gradients of the St. Gothard line.

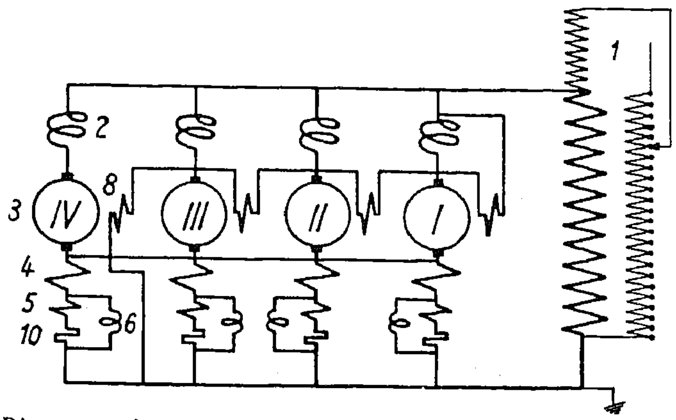


Fig. 16. Diagram of connections for braking, for a locomotive half, in the case of the locomotive No. 11801 of the Swiss Federal Railways.
(For key see Fig. 13)

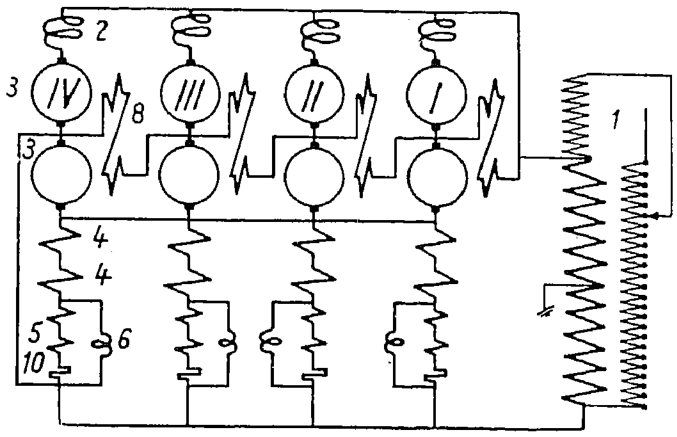


Fig. 17. Diagram of connections for a locomotive half, in the case of the locomotive No. 11851 of the Swiss Federal Railways.
(For key see Fig. 13)

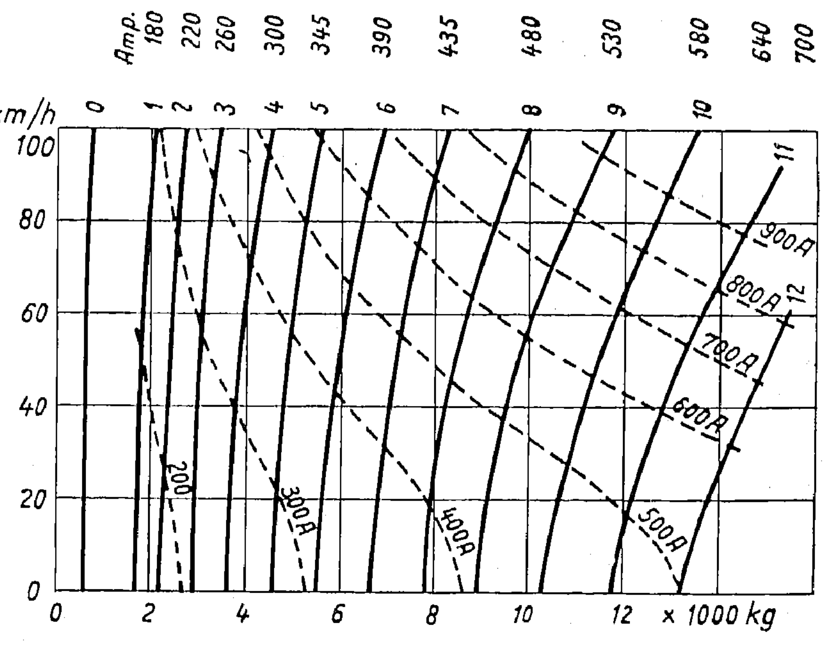


Fig. 18. Curves arrived at by calculation for regenerative braking on the locomotive No. 11851 of the Swiss Federal Railways.

The mode of connection for braking is essentially the same for both locomotives, viz: connecting up of the armature circuit, with the braking choking coil, and of the main field circuit to the same pressure step of the transformer, on the one hand, and to the neutral point terminal of the transformer, on the other hand. The differences in number of motors and in the electrical arrangement of the latter

necessitated, however, some alterations but not of an essential nature (Fig. 16 and 17). The locomotive No. 11801 has 4 driving motors per half locomotive, and locomotive No. 11851 8 motors, the two motors driving the same axle being connected in series. In the case of this locomotive, the central point of the secondary winding of the transformer is earthed, and, in the other locomotive, the end. In this way the pressure during service between motor and earth is limited, in both cases, to the terminal pressure of the motors. In either case, the four armature circuits of each locomotive half are connected in parallel and all 4 or 8 field windings are arranged in series.

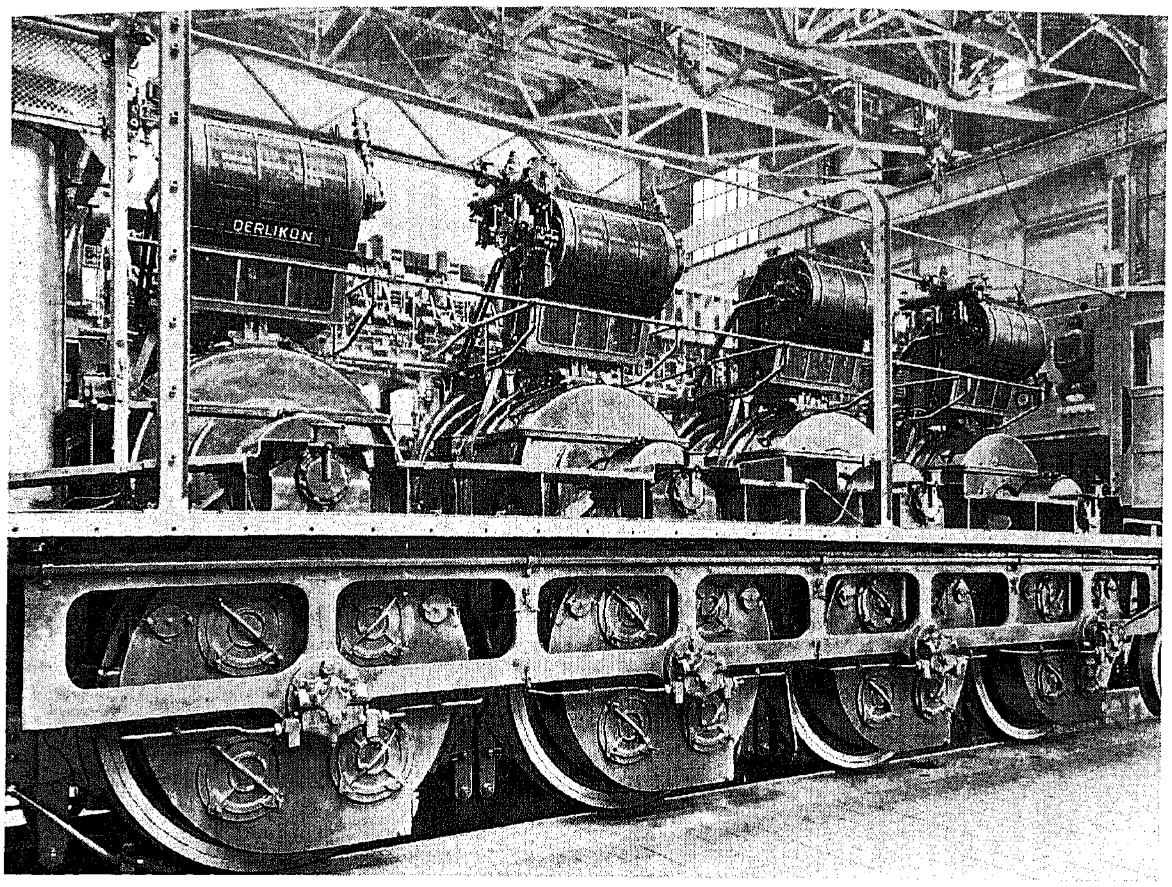


Fig. 20. Mode of assembly of the braking equipment on a 2 D_0 1 locomotive of the Swiss Federal Railways.

The great possibilities as regards regulation of braking force afforded by the Oerlikon regenerative braking system can be seen from Fig. 18, where we have plotted the calculated curves for regenerative braking. The curve 0 represents the braking force due to the friction losses of gears and motors, the curves 1 to 12 the braking forces at different speeds on the steps 1—12, and the curves 200A to 900A are lines connecting the points with same armature current (200, 300, ... 900 amps). The extra weight resulting from the provision of the regenerative braking equipment should amount, for these two locomotives, to about 6.5% of the weight of the total electrical equipment and to not quite 3% of the locomotive weight.

In conclusion it may be asserted as an indisputable fact that electric regenerative braking has come into its own in single-phase traction too. Of course, the conditions on all railways and all sections of line do not lend themselves to the adoption of this mode of braking or, in fact, to any method of electric braking. In cases, however, where the conditions are favourable, i.e. where there are long and heavy gradients, regenerative braking, as evolved by the Oerlikon Company presents, apart from the advantages of any mode of electric braking, such as additional brake independent of the mechanical brake and saving of tyres and brake blocks, the further advantage of having a great braking capacity which makes it possible to deal with a weight up to the total train weight the locomotive can haul up-grade, of ensuring a constant braking force which is independent of the speed of train and acts until the train is at standstill, and of permitting of the recovery of a substantial portion of the power consumed during the up-grade journey, coupled with great simplicity in operation.

The fact that the Swiss Federal Railways have adopted regenerative braking, as evolved by the Oerlikon Company, for no less than 93 motor coaches and locomotives ranging up to the heaviest locomotive, shows conclusively that the great advantages of this mode of braking entirely outweigh the disadvantages which are occasionally quoted as objections to its use.

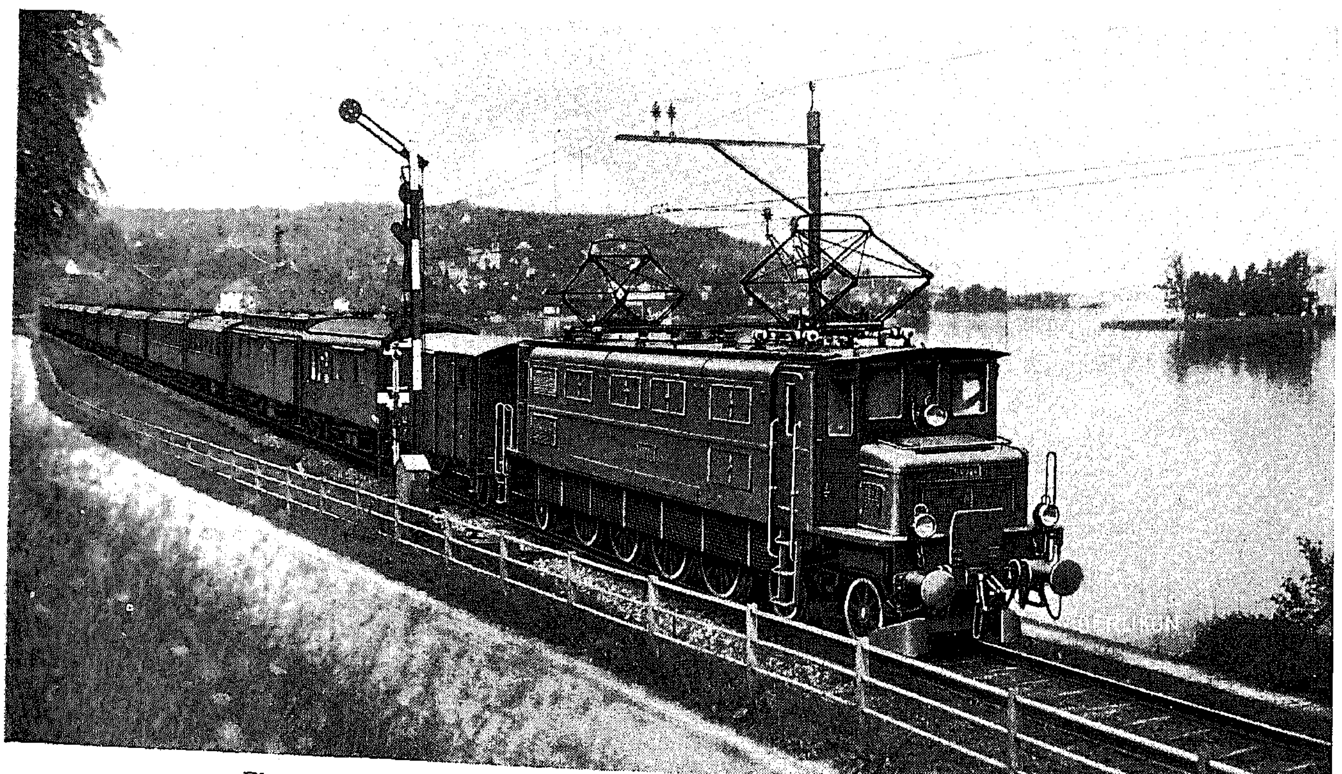
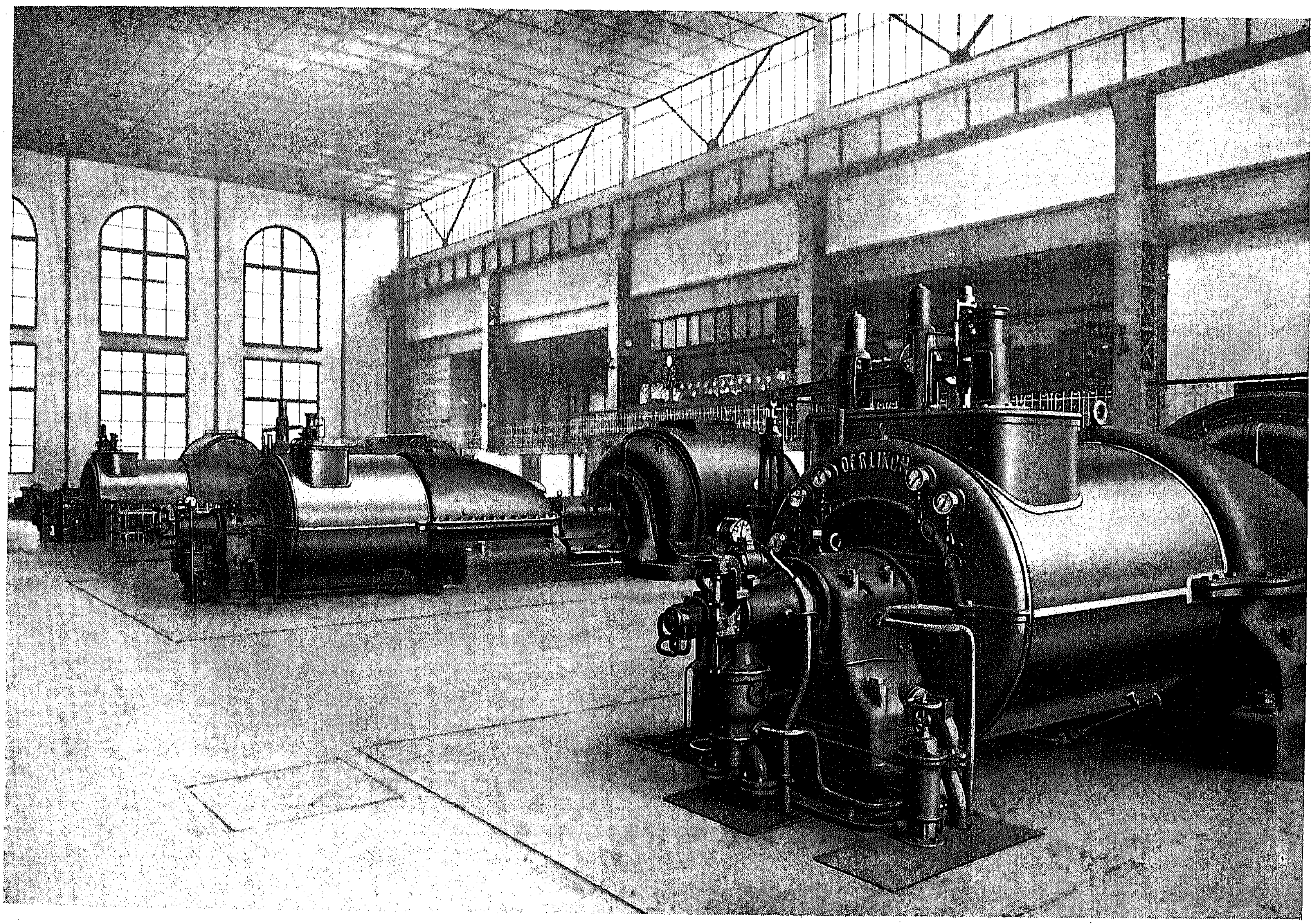


Fig. 19. 2 D_0 1 express locomotive of the Swiss Federal Railways.

BULLETIN OERLIKON

No. 121 — July 1931

Contents:



VILLE-SUR-HAINE POWER STATION OF THE SOCIÉTÉ DE GAZ ET D'ÉLECTRICITÉ DU HAINAUT (BELGIUM) WITH THREE OERLIKON STEAM TURBINES FOR 4,000, 6,000 AND 6,000 KW.

Set I) 4000 KW, 170 lbs./sq. in (gauge), 570° F. Put into service March 1927.
Acceptance tests 20th May 1927 by Professors Vernaux and Vinçotte.
Efficiency 76.5 % in front of inlet valve and turbine outlet flange.

Set II) 6000 KW, 200 lbs./sq. in (gauge), 660° F. Put into service August 1929.
Acceptance tests 7th and 8th November 1929 by Profs. Halleux and Vinçotte.
Efficiency 80.3 % in front of inlet valve and turbine outlet flange.

Set III) As set II). Put into service July 1930.
Acceptance tests 21st and 22nd October 1930. **Efficiency 82.5 %** in front of inlet valve and turbine outlet flange.

Linking up of Power Plants by Transformers with Automatic Load Ratio Control.

By J. Kristen.

Report to the Conférence Internationale des Grands Réseaux Electriques à Haute Tension, Paris, 1931.

Summary. When two distribution systems belonging to different concerns are interlinked, both the exchange of effective power and the distribution of reactive power are fixed by the contract governing the exchange of energy. The types of plant available for achieving this object are the induction regulators and the transformers with load ratio changer. Regulating equipments comprising induction regulators permit of an exchange of power at a power factor with a constant value chosen at will. Within recent years distribution systems have been linked up through the intermediary of lines working at pressures higher than 50 kilovolts. In such cases, series transformers and excitation transformers have to be used in connection with induction regulators. If we compare the cost, we find that the cost of an induction regulator equipment for such voltages is about 15% higher than that of a step transformer equipment. This difference in cost is due, in greater part, to the series transformer. The use of such induction regulating equipments is thus confined to very special cases.

The above considerations have led to the increased application of the transformer with load ratio changer. Owing to its voltage steps, power factor regulation cannot be obtained; in view of this, the procedure is to regulate the reactive power. We are giving here a concrete example to show the conditions governing the design of such an equipment. The exchange of reactive power, shown in the vector diagram, is limited by means of a wattmeter regulating system to a strip with a width depending upon the tap voltage (for instance 2%) and the total impedance of the transmission. The degree of non-sensitiveness of the regulator (adjustable by the tension of a spring) must correspond to the rush of reactive power caused by a tap change. A phase advancer permits of an angular displacement of the strip of regulation shown in the vector diagram, thus allowing of an exchange of reactive power at any desired average power factor different from unity.

The automatic regulation by means of a load ratio changer entails the limitation of the tap changes per unit of time. For this purpose, provision is made for a climbing relay, which at every switching impulse exerts a pull on the adjusting spring of the rotating system, and increases in this way the width of the strip indicating the degree of non-sensitiveness of the regulator. For this reason there is a longer period of time for the necessary tap changes for the regulation of a given rush of reactive power. Particulars are given regarding the designing of a 10,000 kVA step transformer and the arrangement of the wattmeter system with climbing relay.

The installation in question with its automatically controlled step-transformer equipment for linking up distribution systems is the first one to be erected, at least in Switzerland. It is to be hoped that this mode of regulation for interlinked systems devised for the first time by the author in 1925 and now used in connection with step-transformers as described above, will find widespread application.

Power stations are linked up for technical and economical reasons. At the present day, it is hardly necessary to go into this aspect of the question more fully. If we consider the problem of the distribution of energy within interlinked systems from the economical point of view, we have to distinguish between systems belonging to the same concern, and those belonging to different concerns. In the following we shall deal with the conditions governing the interlinking of systems which do not belong to the same concern. In this case, the amount of power to be exchanged in relation to the time is laid down by certain obligations entered into. Let us assume that two systems belonging to different concerns are interlinked by a transmission line. The obligations governing the exchange of power between the two systems are set out in a contract. Each party has the right to consume at a certain time an amount of power or energy within limits stated by the contract. Each party may have to furnish power or energy according to their mutual obligations.

The exchange of effective power through the intermediary of the interlinking transmission line is controlled by the setting of the governors on the prime movers, while the exchange of reactive power is dependant upon the pressure regulation. At the present day, we have at our disposal for pressure regulation the induction regulator and the transformer with load ratio control. The need for such apparatus for controlling the exchange of reactive power in the interlinking transmission line, may be explained as follows. Each concern has to regulate the pressure of its own distribution system according to its own load. This gives rise to pressure variations at both ends of the interlinking line which make the desired exchange of reactive power between the two systems impossible. We need therefore an adjustable link in the transmission line. The problem cannot be solved by regulating the voltage, at will, for a given constant value. For a number of years this interlinking of systems of separate concerns has been proceeding. In this connection induction regulators have been used with very good results. The automatic control of reactive power between the two networks makes it possible to maintain a constant power factor chosen at will, even when the pressures in the two systems vary freely between certain limits.

Owing to the fact that the induction regulator has a continuous curve of pressure regulation, the exchange of energy can be ensured at any desired constant power factor with an automatic power factor regulator. Such a regulator must have a sufficient degree of sensitiveness for low currents, and its regulating properties must not be affected by normal pressure variations. The arrangement of such a regulating equipment was described for the first time in the Bulletin of the Swiss Association of Electrical Engineers, (S. E. V.), Volume No. 10, 1925. Descriptions of stations equipped with this apparatus can be found in the Report No. 420, Section 20, World Power Conference, Berlin.

Within recent years, the linking up of systems has been done in most cases, by means of transmission lines operated at more than 50 kilovolts. Induction regulators suitable for direct connection in the line have been built up to 20—25 kilovolts. This means that when induction regulators are resorted to for high voltages, this plant has to be used in conjunction with an excitation transformer and a series transformer. When the interlinking of systems is combined with transformation of pressure, it is customary to replace the excitation transformer by a third winding on the main trans-

former. In other cases, the excitation transformer is combined with an auto-transformer, the function of which is to correct the regulating range with a view to the better utilisation of the boosting or bucking action of the regulating equipment. Another advantage derived from the complete transformation is the separation of the currents to earth of the two systems. As the use of a series transformer cannot be avoided, the adoption of regulating units comprising induction regulators is a doubtful proposition from an economical point of view. If we compare the cost of these two means of regulation, we obtain approximately the following results:—

	Induction Regulator	Transformer with Ratio Changer
Main transformer	100	116
Regulator	37	25
Series transformer	26	—
Total	163	141

The above figures allow for the fact that with auto-connected induction regulators with change-over switch the regulators are designed only for half the internal capacity of the regulating unit. For higher voltages, the cost of the induction regulator equipment is approximately 16 % higher than that of a unit with transformer provided with load ratio changer. This difference in cost is due nearly exclusively to the series transformer. As long as the ratio changer equipment does not require a series transformer, it should be given preference for reasons of cost. On the other hand we have to bear in mind that the induction regulator requires more room, works with slightly greater losses and consumes more reactive power. The total consumption (100 percent) in reactive power, of an induction regulator equipment is made up as follows: 73 percent main transformer, 17 percent double induction regulator, 10 percent series transformer.

The main transformer consumes by far the greatest amount of reactive power; this has to be taken into account in the case of either method of regulation. Under these conditions, the economical application of induction regulator equipments must be confined to very special cases.

For these economical reasons, attention has been mainly directed in recent years to the transformer with load ratio changer. This method of regulation is characterised by the fact that the whole pressure regulating range is divided into voltage steps. This stepwise pressure regulation affects the exchange of reactive power in the interlinking line in such a way, that automatic power factor regulation such as used with induction regulators, is not possible. This is due to the decrease in effective power, on a given voltage step, causing a too great variation of the power factor. The Oerlikon Company have adopted the method of regulating the reactive power, whenever regulating units with ratio changers are used. We propose to describe an automatic regulating equipment provided with a load ratio changer.

We shall take, for the purpose of illustration, the definite case where the two systems are linked up by a transmission line. According to Fig. 1, the voltage of one system is P_1, which quantity varies between 130—140 Kilovolts. The transformer (T) with ratio changer is fed by this system at that pressure. The second system is connected to the transformer through a sixty mile transmission line. The pressure of the latter varies between 58.20—60—64.80 Kilovolts. The impedance of the transmission line is $Z_l = (17 + j42.5)\ \Omega$. The exchange of energy takes place in either direction. During the flow of energy from the system 1 to the system 2, the power factor of the regulating transformer is $\cos\varphi = .8$ during the day, and $\cos\varphi = .7$ at night, while the pressure P_1 may vary between 135—140 Kilovolts. During the flow of energy from the system 2 to the system 1, the power factor of the regulating transformer is $\cos\varphi = .92$ during the day, and $\cos\varphi = .85$ at night, while the pressure can be taken as 130 Kilovolts. The above defines the conditions governing the exchange of energy.

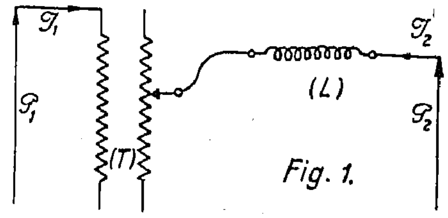


Fig. 1.

The current diagrams, as generally described in the S. E. V. Bulletin, Volume No. 10, 1925, show clearly the manner in which the pressure is regulated with step transformers. When all quantities are converted to their equivalents on the 135 Kilovolt side of the step transformer, we have the following equation for the current:— $J_1 = \left(\frac{P_1}{Z_{k\,12\,x}}\right) - \left(\frac{P_2'}{Z_{k\,12\,x}}\right)$. x denotes any desired tapping on the step-transformer. This tapping corresponds to a number of secondary turns W_{2x}. The number of primary turns is W_1. The turn ratio can be set down as $U_{12x} = \left(\frac{W_1}{W_{2x}}\right)$. If we make use of this expression, the pressure P_2 converted to its equivalent on the primary side is $P_2' = U_{12x} \times P_2$. The total impedance of the transmission can be set down as $Z_{k\,12\,x} = (Z_{t\,12\,x} + U^2_{12\,x} \times Z_l)$. In the above formula, $Z_{t\,12\,x}$ denotes the short-circuit impedance, measured at the primary terminals of the step-transformer on tapping x. The 10,000 kVA step-transformer has a regulating range of $\pm 20\,\%$ over ± 10 steps. The turn ratio varies between 1.80 and 2.71. It was possible by adopting a suitable design to ensure a constant wattless component of the short-circuit pressure, namely 11.5 % over the working range, while the watt component has a constant value of approximately .5 %. As the variable turn ratio affects the impedance of the transmission line, we have, if we convert it to its equivalent on the primary side, a total impedance of transmission varying between 333—520 Ω between the extreme positions of the ratio changer.

Fig. 2 shows the current diagram of the transmission. The voltage $P_1 = 135$ Kilovolts is constant. The voltage P_2 is 60 Kilovolts (circles drawn in full line) or 64.80 Kilovolts (circles drawn in dotted line). The current diagram is plotted for every second step (± 0, ± 2, ± 4, ± 6, ± 8, ± 10). We can see from these diagrams that the variation of reactive power per step amounts at the most to the constant value: $4.375 \times 135 \times \sqrt{3} = 1000$ kVA. This is true when the pressures at the ends of the interlinking line are not influenced by a change of tapping. If this is not the case, the rush of reactive power, when switching over from one tapping to the other, is even smaller.

In order to be able to obtain power factor regulation by means of the above step-transformer, we have to adjust the degree of sensitiveness of the regulator to the ± 500 kVA rush of reactive power, otherwise the automatic regulator will cause switching forwards and backwards, which, in this

case, is very undesirable. Fig. 3 shows a method of regulating the reactive power complying with the requirements mentioned above. (13) denotes the step-transformer with its ratio changer (12). The control current is led through a switch box (10) to the reversing switch (11). When the handle (3) is set for "hand operation", the depressing of the push button switch (9) causes the ratio changer to move in either direction. When the handle (3) is set for "automatic operation" the two pilot contactors, belonging to regulator (1) cause the reversing switch (11) to operate. When the two conductors (1, 2) are connected together by a pilot contactor, the ratio changer moves forwards, while the linking up of the connectors (3, 4) makes the ratio changer move backwards. The pilot contactors are controlled by a double-pole, double-throw switch with mercury contacts. This switch is mounted on the rotating part of an electro-dynamometer with an iron core as magnetic circuit. The angular deflec-

resulting from a change of tapping. This adjustment is ensured by a spring acting on the rotating part of the regulator. The strip of regulation is not comprised between two exactly parallel lines, as shown in Fig. 4, as the degree of non-sensitiveness of the regulator increases slightly with decreasing current. Measurements have shown that the degree of non-sensitiveness does practically not change when

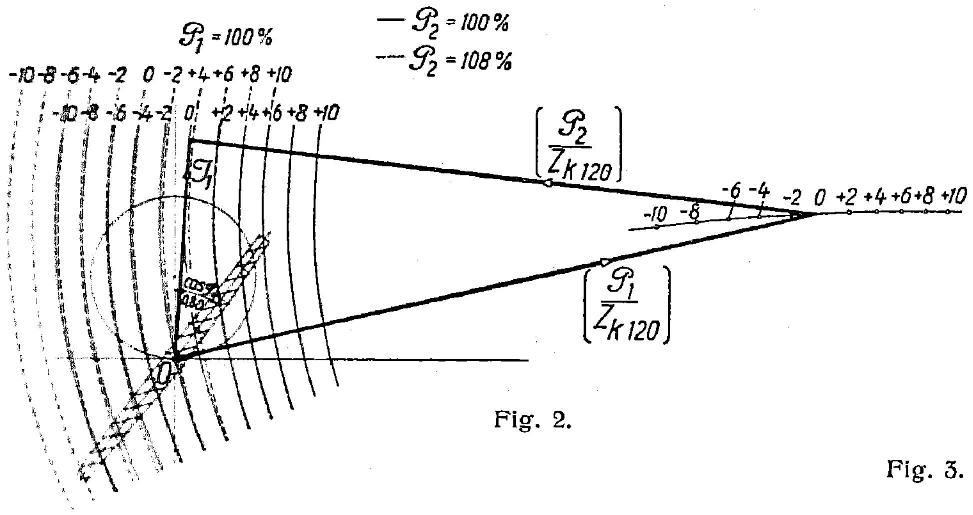


Fig. 2.

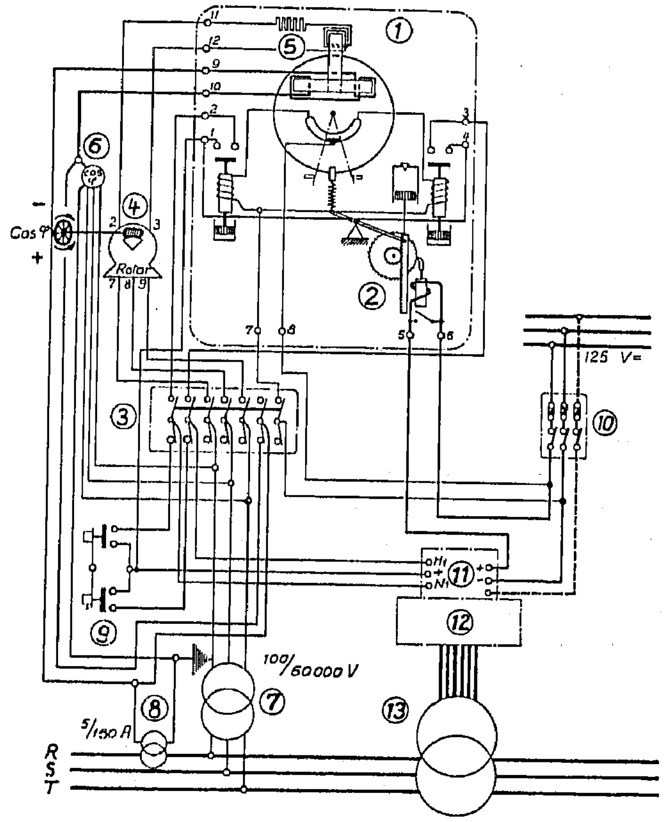
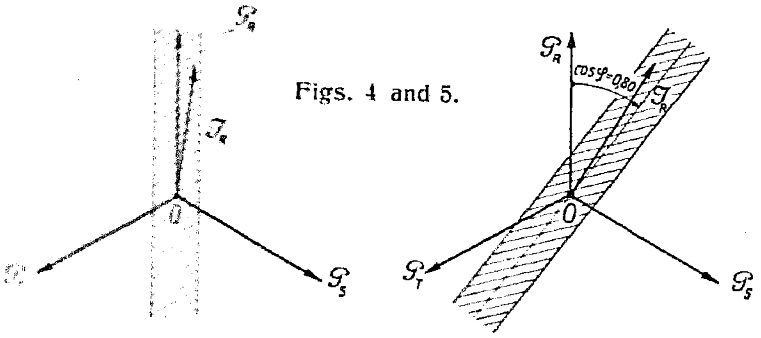
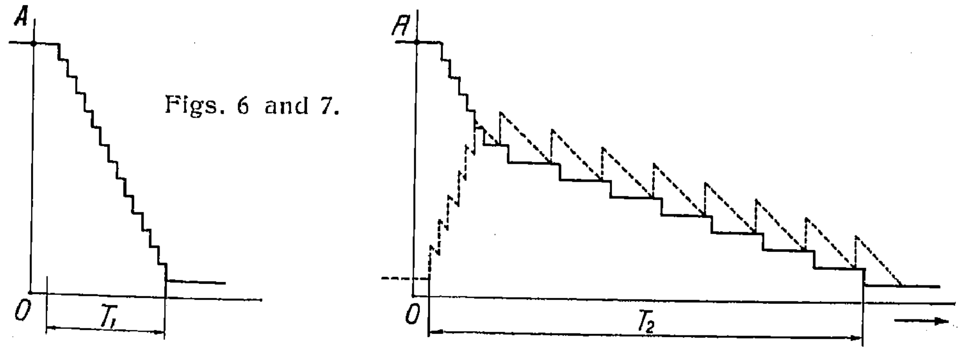


Fig. 3.



Figs. 4 and 5.



Figs. 6 and 7.

tion of the rotating part is caused by a wattmeter system, the current coil conductors (9, 10) of the latter being energized by a current transformer (8) in the phase (R) of the system. The voltage coil conductors (11, 12) of the wattmeter system in series with the resistance (5) are connected to the secondary terminals of the phase advancer (4). The primary side of the phase advancer (7, 8, 9) is fed by a potential transformer (7). The purpose of the phase advancer (4) is to give, on its secondary side, an adjustable voltage vector having any desired direction. If we adjust the voltage between the terminals (2, 3) in such a way that it is in phase with the line voltage (S-T) of the system, the wattmeter system limits the exchange of reactive power to the strip shown in the vector diagram Fig. 4. The width of this strip is dependant upon the degree of non-sensitiveness of the rotating part of the regulator. The degree of non-sensitiveness must correspond to the rush of reactive power

the rated voltage varies no more than ±20 %. The diagram, Fig. 4, shows the phase advancer in a position for regulation at an average $\cos\varphi = 1.0$. If it is desired to obtain regulation at a different average value of power factor, $\cos\varphi = .80$, for instance, the voltage vector (terminals 2, 3) has to be shifted through an angle φ towards the vector of the line voltage (S—T). This condition is shown in Fig. 5. The strip of non-sensitiveness is shifted through the same angle as the vector of the voltage (2, 3). The exchange of reactive power in the interlinking line is kept by the regulator within the limits of the inclined strip shown in Fig. 5. We can further see that if the degree of non-sensitiveness of the regulator is kept the same, the variation of reactive power increases $1/\cos\varphi$ times.

The method described above is a method of regulating the reactive power with an accuracy limited only by the rush of reactive power when making a change of tapping. On

the other hand, according to Fig. 5, it is possible to maintain by means of the phase advancer an average power factor, different from unity.

The induction regulator permits of a voltage regulation without any interruption of current. In the case of transformers with load ratio changer a sufficient interval has to elapse between changes of tapping, to allow the gases, produced in the oil circuit breakers, when interrupting the current, sufficient time to escape. The necessary interval between changes of tappings can be ensured by a climbing relay (2). The starting current of the motor, driving the ratio changer, operates a solenoid (5, 6) which through the intermediary of a pawl and rack lifts a dash-pot piston a certain amount whenever a change in tapping is made. An adjustable valve permits of the regulation of the time required by the piston to drop back to its starting position. If many changes in tappings follow at short intervals, there is not enough time for the piston to drop completely, and the latter keeps on moving upwards and finally closes an auxiliary switch which locks the whole automatic regulator for an adjustable predetermined period of time through the intermediary of a time relay. As far as we know, such interlocks have actually been manufactured. The drawbacks of such an arrangement are obvious. It is undesirable that the regulator should be out of action during the time of interlocking. For this reason, the Oerlikon Company have evolved, in co-operation with the Bernese Power Supply Co., a different locking device with a view to increasing the intervals between changes in tappings, before the piston of the climbing relay has reached its top position. This is done as shown in Fig. 3 by connecting the dash-pot piston of the climbing relay to the adjustable spring on the rotating part of the regulator. Every switching impulse received by the solenoid of the climbing relay causes the expansion of this spring, so that the tension of the spring increases as the dash-pot piston moves upwards. The strip in Fig. 4 representing the degree of non-sensitiveness of the regulator widens. This increases the intervals between the changes in tappings which are necessary for the regulation of a certain rush of reactive power. In view of this, the locking time relay has to operate only in very exceptional cases. Tests have shown that by using the right kind of spring, it is very easy to obtain a sensitiveness such as corresponds to the rush of reactive power of a change of tapping, provided the spring is not stressed. The above rush of reactive power represents about 5 % of the total amount of kVA to be transmitted, and when the spring is fully loaded, the degree of non-sensitiveness is raised to correspond to 40—50 %. Fig. 6 gives an example of regulation with this kind of equipment. OA represents a rush of reactive power in the system. The two diagrams show how this rush has been regulated in respect to the

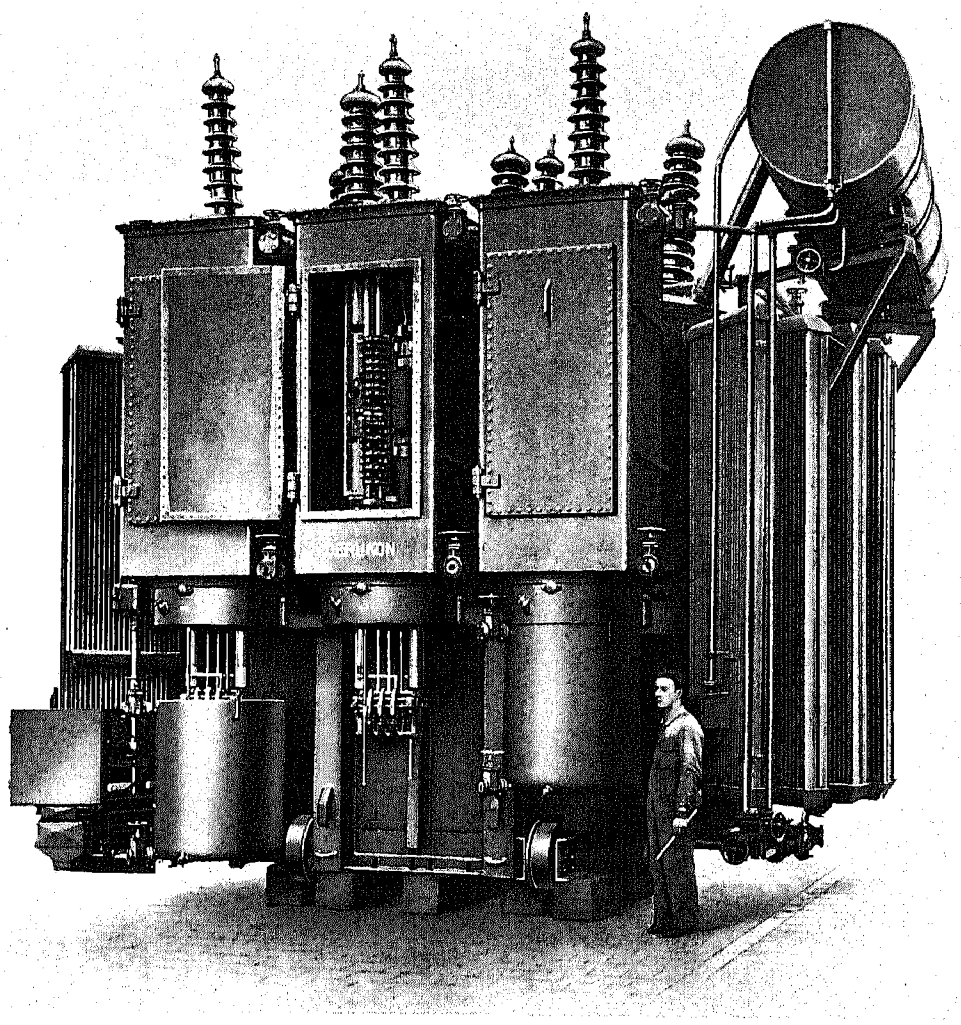


Fig. 8.

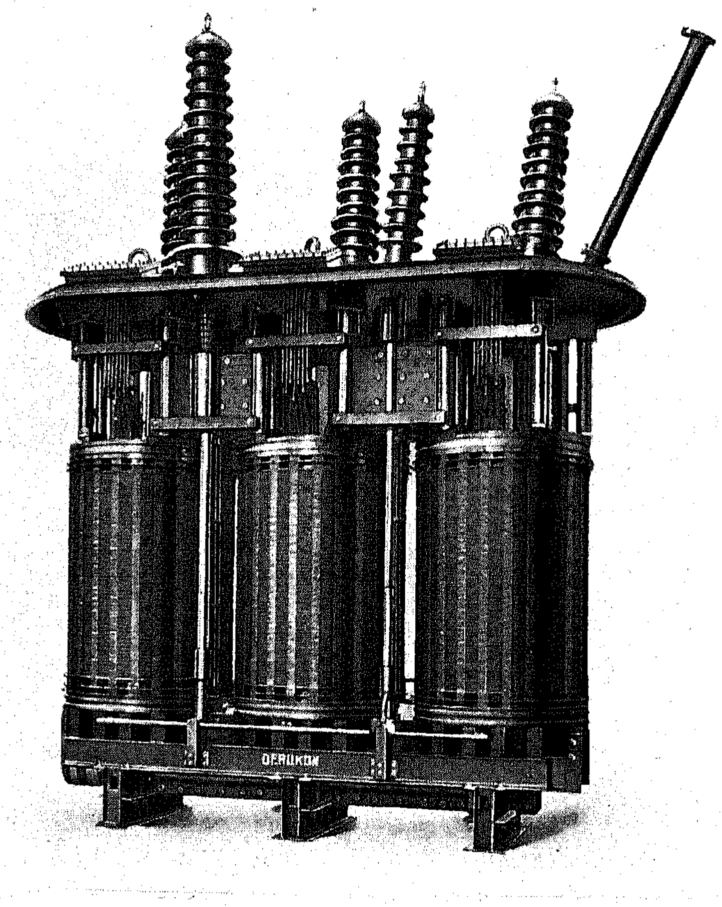


Fig. 9.

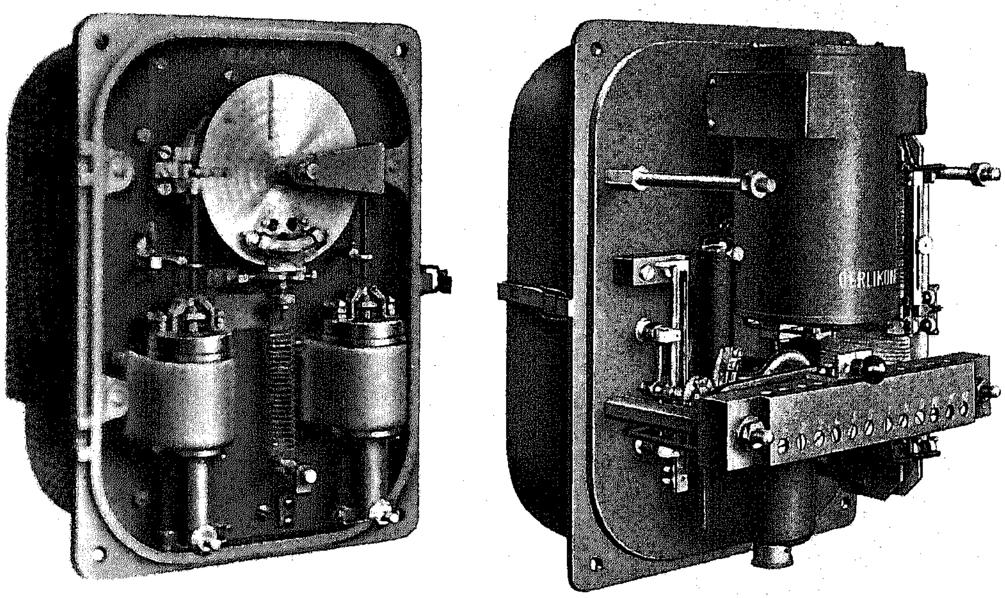
time, in the first place by a relay with interlocking contact in the end position of the piston, secondly by the blocking arrangement shown in Fig. 3.

The diagram, Fig. 6, shows the reactive power in relation to the time, when the first method of locking referred to is used. The initial rush OA is reduced in steps by a number of changes in tappings, until the amount corresponding to the degree of non-sensitiveness of the regulator is reached. Complete regulation takes place within the time T_1 provided the dash-pot piston of the climbing relay does not reach its top position earlier and cause the locking of the regulator. The diagram Fig. 7 shows the conditions when use is made of an equipment according to Fig. 3. The same initial rush OA is assumed. The step-like curve shown in full line, represents the reactive power in relation to the time. The time for complete regulation of the rush OA is now increased to T_2 which quantity can be set by adjusting the time for the complete downward motion of the dash-pot piston of the climbing relay. The curve drawn in dotted line gives the degree of non-sensitiveness expressed in its equivalent of reactive power; it is affected by the tension of the spring.

The whole regulating equipment is built for outdoor mounting. Fig. 8 shows the 10,000 kVA transformer, with its ratio changer, each phase being enclosed in a separate built-on casing. The reversing switch on the left hand side drives the ratio changer through a common shaft.

The design of the parts inside the tank, the drum type tapping selector switch and the reactance coil for bridging purposes can be clearly seen in this picture. The switchgear for operation on load is in the form of a high speed oil circuit breaker with double interruption, built on to the tapping selector switch. The oil tank of the circuit breaker can be lowered for inspection purposes. Fig. 9 shows the whole active part of the transformer. Fig. 10 and Fig. 11 are front and rear views of the regulator denoted by (1) in Fig. 3. The disc carrying the double-throw mercury switch, is clearly visible in Fig. 10. The disc is revolved by a fork belonging to the rotating part of the regulator and projecting over the base. The adjustable spring is secured at the same place. The lower end of the spring is displaced by a lever operated by the climbing relay (2) which is fitted at the back of the regulator. The pilot contactors, mounted on both sides, energize by means of their operating core, the reversing switch and reset the disc through the intermediary of a system of levers. The time for the complete lift of the core can be varied. Fig. 11 also shows the terminal board, the adjusting resistances and, at the top, the wattmeter system with its vertical spindle. On the left, is mounted the climbing relay (2). The solenoid with the pawl is visible in the foreground, and behind it is the dash-pot with the adjusting diaphragm of the air valve.

This automatically controlled load ratio changing equipment for linking up systems is the first one to be erected, at least in Switzerland. This mode of regulation for interlinked systems was, for the first time, suggested by the author, in 1925. It is to be hoped that the method such as described above and now used in connection with step transformers, will find widespread application. The requirements of the service and the experiences of recent years have helped to make these ideas more fully appreciated even by those who formerly fought them.



Figs. 10 and 11.

NOTES AND NEWS ITEMS.

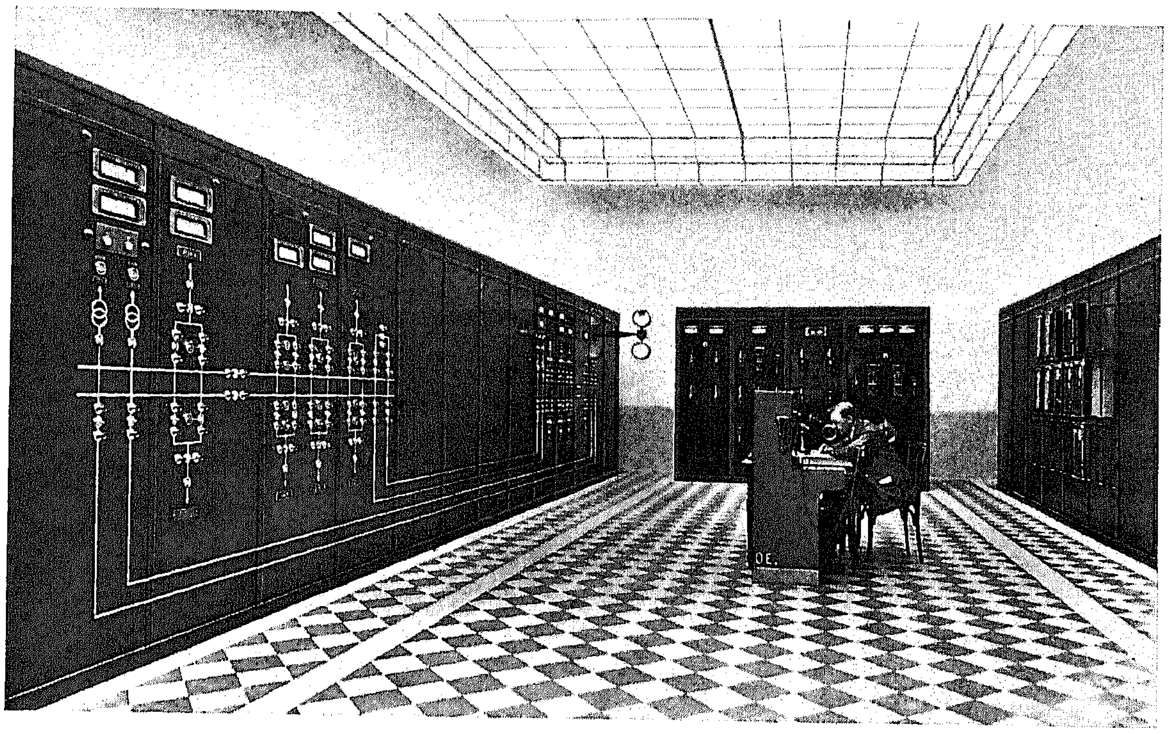
The Mimic Busbar System of the Villejuif Interconnecting Station of the Union d'Electricité, Paris. With a view to interlinking the power stations of the Paris district, the Union d'Electricité have erected at Villejuif an important interconnecting station which according to the practice of this Company embodies all the latest improvements. The control room, in particular, which constitutes the vital point of the installation has received special attention.

The Oerlikon Company which had already supplied to the Union d'Electricité the mimic busbar system of the Gennevilliers Power Station has been entrusted with the task of studying and building the whole switchboards for the Villejuif interconnecting station. The principal part is the mimic busbar system which has a length of about 33 ft, where the whole diagram of connections of the station is reproduced by nickeled bars.

The circuit breakers and isolating switches are represented by lamps with miniature switches which can be placed in line with the bars or transversally so as to give the "on" and "off" positions of the gear itself. The lamps are normally out and become alight when for some reason the position of the gear does not correspond to that of the miniature switch of the lamp. The circuit breakers and the isolating switches are operated from the switchboard by means of pull-buttons arranged on the side of each pilot lamp and interlocked with them. The different protective relays are

mounted at the back of the mimic busbar system. There is opposite this mimic busbar system a switchboard of same dimensions carrying the recording instruments. The switchboard for the auxiliary services is at one end of the room, while two panels for the meters are arranged on either side of the door of the room at the other end.

The wiring has been carried out with the greatest care and with a view to rendering the connections as clear as possible. All the wires are fixed individually by means of small brass clamps on marble slabs fitted behind the switchboard on both sides of each panel. The cellulose paint used for these switchboards has been made according to the processes utilised for motor car coachwork of the highest quality and helps to give to the whole of the room a very pleasing appearance.



Winding Gear for Rope Haulage Operated Directly off a Three-phase 3000 Volts, 50 Cycles Supply. The following description refers to winding gear supplied in 1930 by the Oerlikon Co. for an installation in Spanish Morocco. This plant, which is represented in Figs. 1 and 2, is built for a double haulage, loaded trucks being hauled, while empty trucks are let down; the track has a constant gradient of 1 in 2.24 and a length of about 490 feet. The main data are as follows:— Working load = 9700 kgs. (21 300 lbs); Dead load = 6800 kgs. (14950 lbs); Weight of the 1½" steel rope = 4.2 kg/m. (2.8 lbs per ft. run); Resulting tractive effort at the beginning of hauling operation = about 5200 kgs. (11 400 lbs), at the end of hauling operation = about 4700 kgs. (10300 lbs); Hauling speed = 1.65 m/sec. (5.4 ft/sec). The design of the mechanical part of the winding gear is in its general lines the same as in the case of the reel type winding gear, described in detail in Oerlikon Bulletin No. 94 of 1929. The main shaft is carried by three ring lubricated bearings mounted on a frame of section iron and plate, of substantial construction and suitably stiffened. This shaft carries two cast iron drums with a winding diameter of 2 metres (6.56 feet) and each with a winding width of 1 metre (3.28 feet). These drums each serve to take a steel rope 170 metres (558 feet) long, wound in one layer; they are grooved so as to ensure correct winding, and with a view to protecting the rope. One of the two drums can be adjusted in relation to the other, a clutch being provided to permit of this adjustment. During the latter operation, a holding brake in the form of a band-brake, serves to hold the uncoupled drum. A mechanical locking device is provided between the holding brake and the clutch which prevents the clutch from being disengaged before the brake is applied and the brake from being released before the clutch is put on. The emergency brake, which is designed as a drop-weight brake, is a block brake; it acts on a brake rim cast on the fast drum. This brake is brought into operation either by the attendant, by pressing on a foot lever, or by the depth indicator. When the brake comes into play, the brake weight lever operates the emergency switch referred to below, and the latter in turn causes the release of the main circuit breaker by opening the circuit of the no-volt coil.

The drum shaft is driven by the motor through single reduction gear. The shaft of the motor pinion is

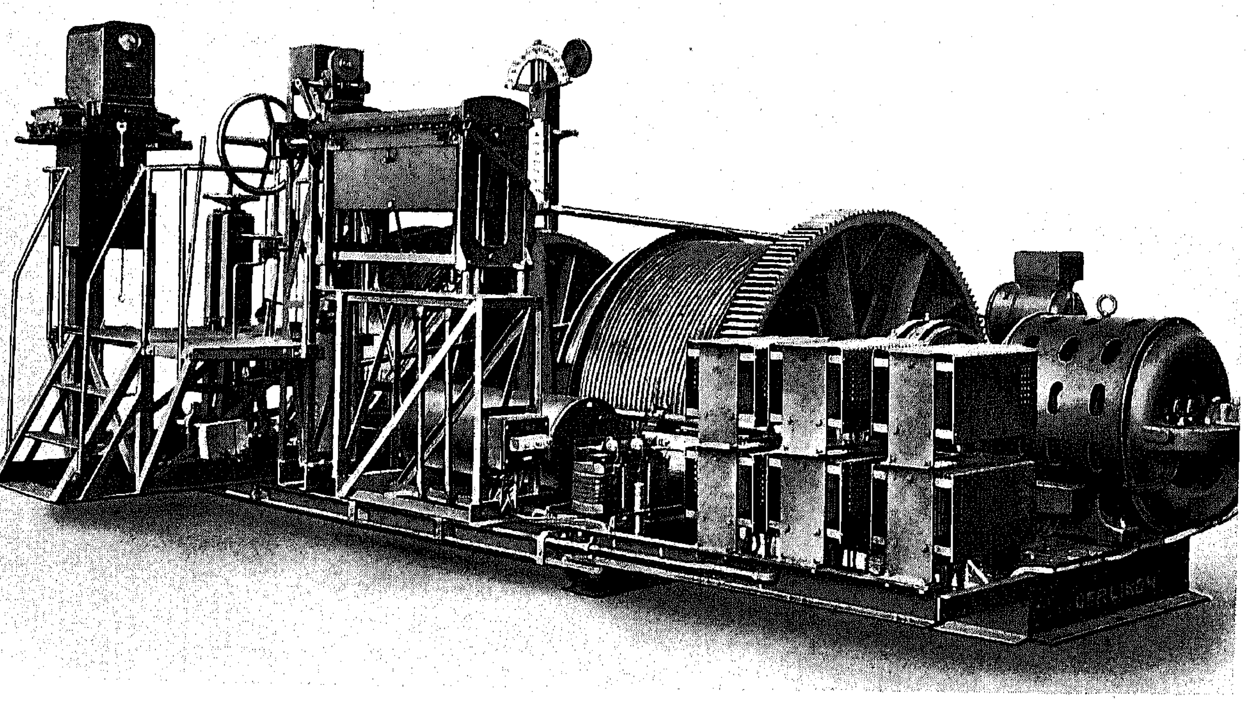


Fig. 1.

flexibly coupled to the motor shaft by means of a coupling with brake pulley. This brake pulley serves for the automatic control brake which is designed as a band brake and operated by a brake lifting motor. A depth indicator of Oerlikon standard design gives to the attendant the position of the trucks at any time. In order that the attendant should have a good view of the winding gear and of the upper unloading point, the control platform is raised.

A special feature of the electrical equipment is the fact that H. T. current is used directly for operating the plant. The equipment comprises the driving motor with built-on centrifugal switch, the master controller, the brake lifting motor for the control brake and the release motor for the emergency brake, the emergency circuit breaker and finally, the main circuit breaker and a small transformer.

device which is operated by the travelling nuts on the depth controller with handwheel operating gear; it controls a stator switch and a controller for the rotor; these are mounted independently on the frame of the winding gear. The stator switch is a double-pole H. T. change-over switch with hammer contacts immersed in oil.

In order to facilitate overhauling, the oil tank of the circuit breaker is arranged in such a way that it can be lowered. As the rotor pressure is considerably lower than the stator pressure (the former is about 500 volts, while the latter is 3000 volts), it is possible to use for the rotor controller a design such as usually adopted for standard Oerlikon controllers, for lifting plant. The common operating rods for the stator switch and the rotor controller have been designed in such a way that it was not necessary to make the rotor controller reversible.

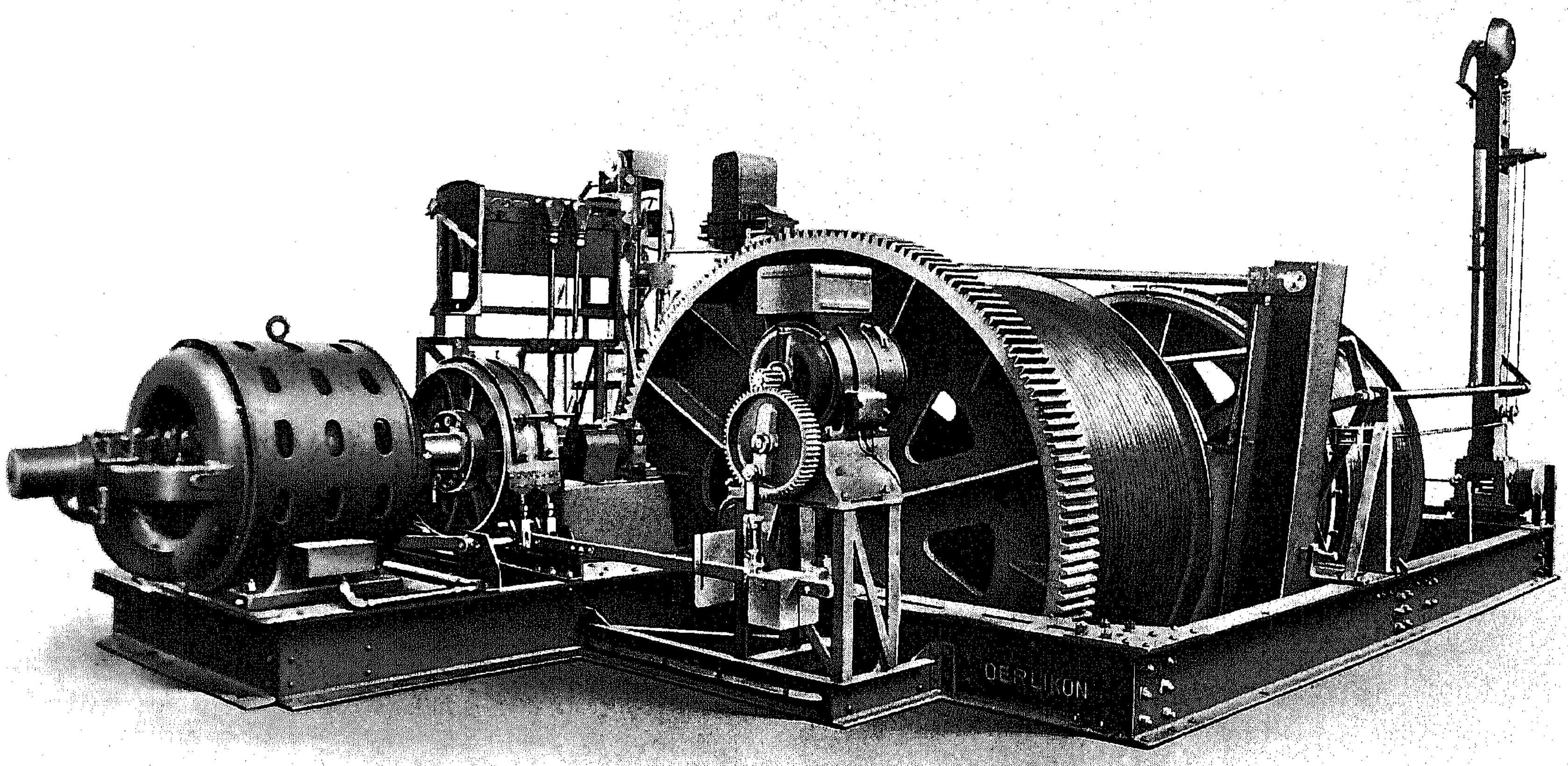


Fig. 2.

The driving motor is a three-phase induction motor of open design; it is connected directly to the 3,000 volt, 50 cycle, H. T. system, through the main circuit breaker. The output of the motor is 140 H. P. for a relative switching-in period of 75 %. The output for starting is 200 HP. and the speed 730 R. P. M.

In cases where loads are lowered and consequently drive the motor, the latter runs as an induction generator at a higher speed than synchronous speed and supplies energy to the system. In order to prevent in such a case the speed from rising too high, which might occur if, for instance, the rotor resistances are left inadvertently in circuit, the second shaft end of the motor is fitted with a double pole centrifugal switch which closes the circuit of the release motor of the emergency brake when the motor reaches a speed of about 1000 R. P. M. This causes the release of the emergency brake and the plant is thus brought to a standstill. The motor is started up and reversed by means of a master

The master controller is provided with an interlocking indicator. This device comes into play when the trucks have reached their end position and the plant has, therefore, to be brought to a standstill by the attendant; il prevents the possibility of the attendant starting up the plant in the same direction as before, inadvertently.

A transformer with a capacity of 1.5 K.V.A. serves for supplying three-phase current at 500 volts to the brake lifting motor of the control brakes, to the release motor of the emergency brake and to the no-volt coil of the main circuit breaker.

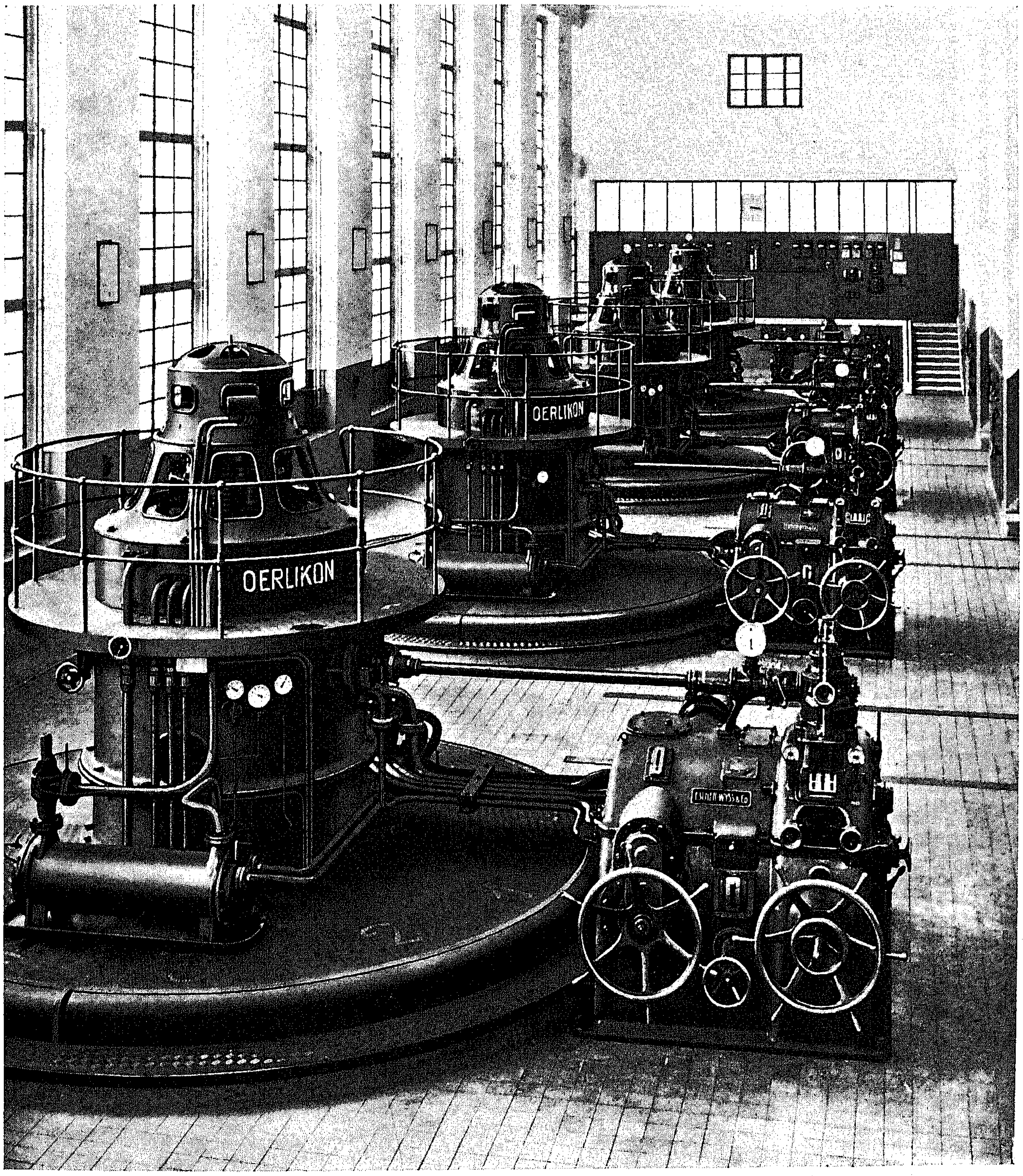
The main circuit breaker is a triple-pole oil-circuit breaker with double interruption of current and automatic release by means of over-load trip-coils in two phases and no-volt coil. There is no step resistance as the insulation of the motor has been so designed as to eliminate all danger of breakdown of terminal coils when switching during normal operation. The switch box is provided with built-on ammeter and is interlocked in the usual way.

ATELIERS DE CONSTRUCTION OERLIKON, OERLIKON

BULLETIN OERLIKON

No. 122 — August 1931

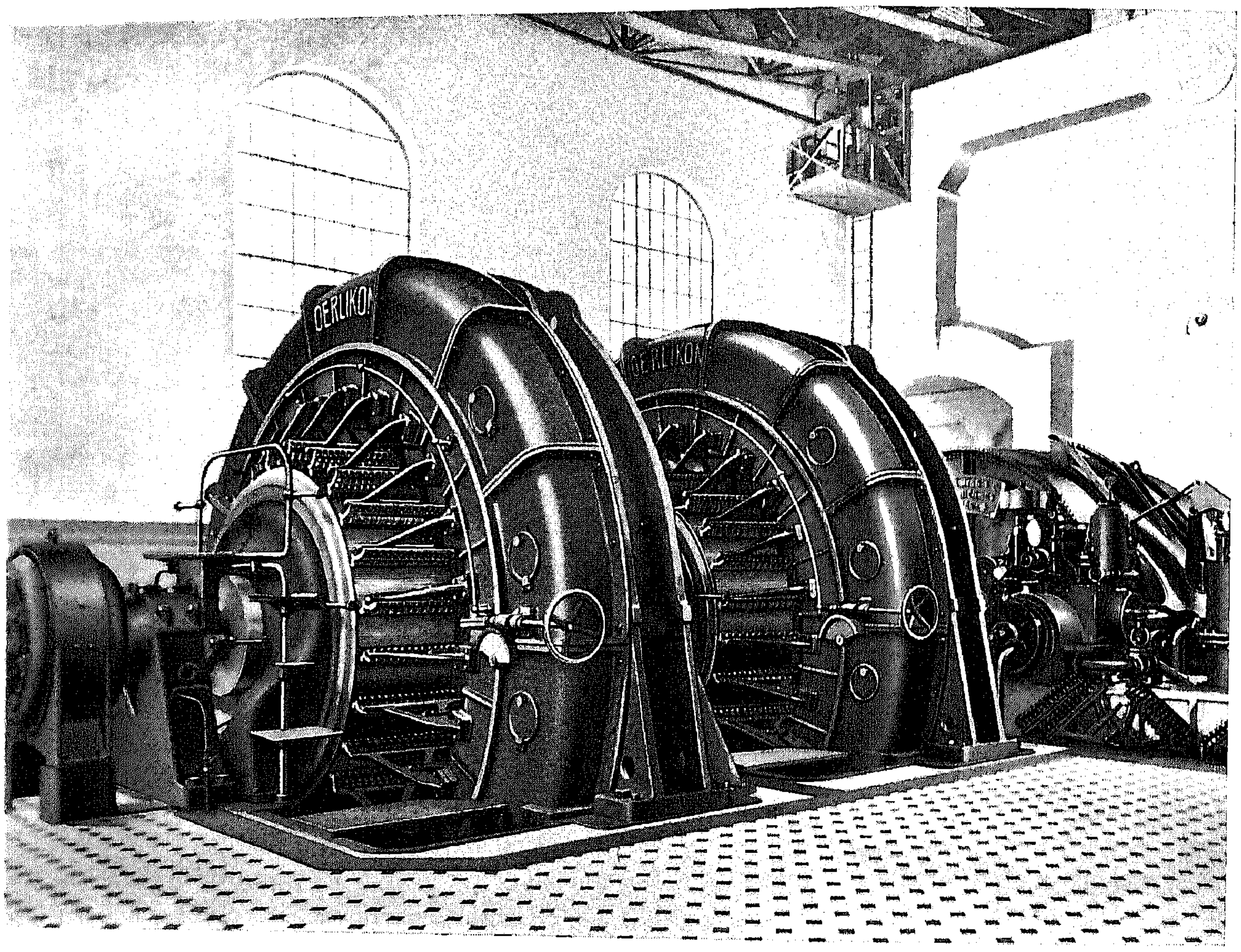
Contents: OERLIKON Machines in the Norvegian Nitrogen Industry.
Three-phase generators for the Oberhasli Power Supply Company.



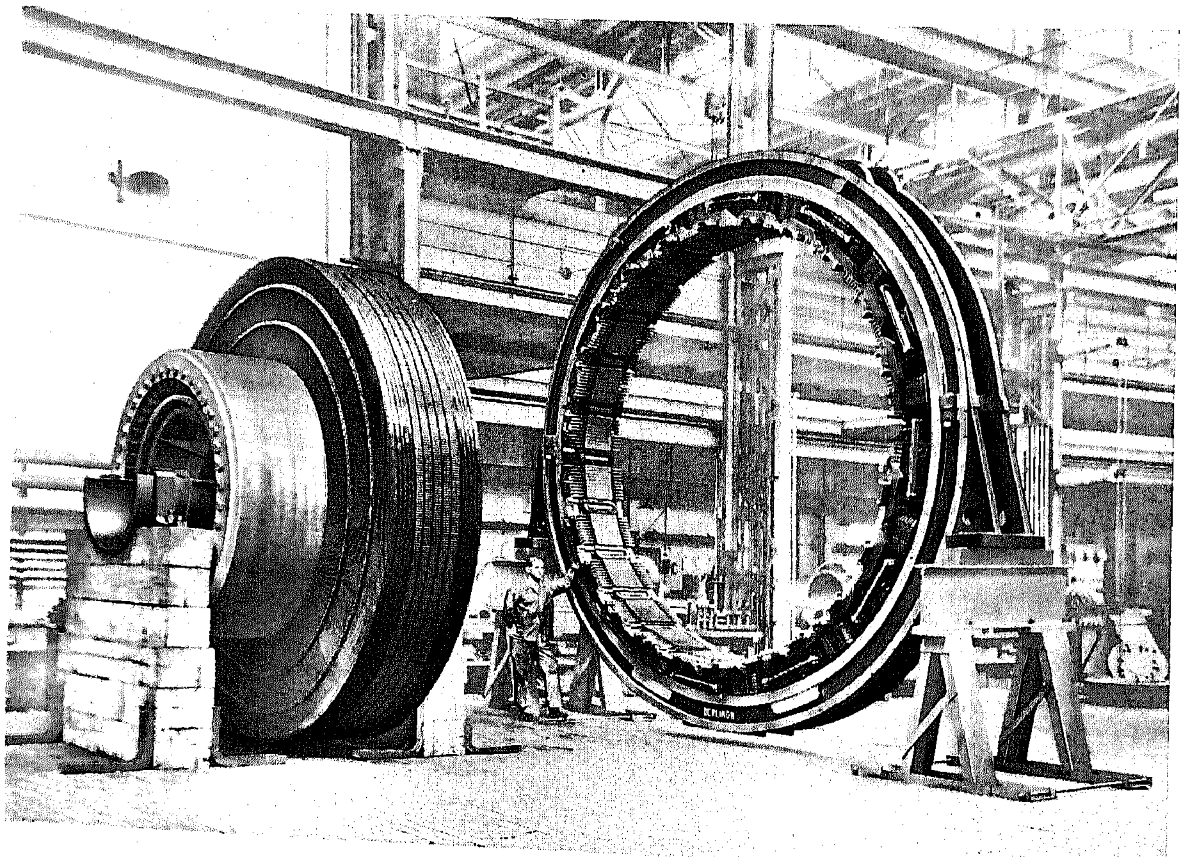
MACHINE ROOM OF THE HANDECK GENERATING STATION OF THE OBERHASLI POWER SUPPLY CO. WHERE FOUR 32,000 KVA OERLIKON THREE-PHASE GENERATORS ARE INSTALLED.

Only the upper part of the sets are visible in this view. The generators themselves are arranged on an intermediate floor. A short description is to be found at the end of this issue.

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Vemork Power Station. - One of the Oerlikon generator sets for 12,000 KW, 470-540 volts, 2 × 12,000 amps., 250 rpm.



Armature and stator of one of the 8 D.C. generators for 6,000 KW, 12,000 amps, for the Vemork Power Station.

Oerlikon Machines in the Norwegian Nitrogen Industry.

The fact that Norway is very rich in water power has contributed, to a very considerable degree, to the important development, in that country, of the nitrogen industry which is dependent upon a cheap supply of electrical energy.

As far back as 1905, the production of nitrogen was started in Norway on a large scale by the Norsk Hydro A.S., the method used being the Birkeland-Eyde process, a process specially suited to the conditions at the time. With this method, the air is driven through an A.C. H.T. arc constituting a disc of flames. The nitrogen of the air burns at about 3000° C (5400° F) and forms nitric oxide. This process has necessitated the supply of large quantities of A.C. energy with an arc pressure of about 4000 volts.

The Norsk Hydro A.S., have erected, for the supply of this energy, large hydro-electric generating stations in a mountain valley (Telemarken) west of Oslo where the conditions are very favourable for the utilisation of the water power. Mention can be made, in particular, of the two generating stations of Vemork and Saaheim which are each equipped with plant having a total capacity of about 180,000 HP.

The power generated at the Vemork power station, where the equipment comprised, in the first instance, ten 17,000 KVA three-phase generators at 10,000 volts, was originally transmitted by means of a number of overhead lines at that pressure to the Works No. I at Rjukan, about 3 miles lower down the valley, and was used there for the production and the refining of nitrogen and different nitric compositions.

The second generating station, that of Saaheim, was provided at the outset with nine 19,800 KVA three-phase generators and supplies still at the present day the energy of 10,000 volts to the Works No. II at Rjukan.

As in the case of most electro-chemical works, experience has shown that the generators have to meet very exacting requirements, as they have to remain in service continuously and are subjected to frequent overloads and to detrimental effects of the arc furnaces on the windings. In view of this, the Norsk Hydro imposed very severe conditions upon the makers of the machines when further plant was installed at the two power stations.

The Oerlikon Company, who have had experience in building machines for electro-chemical purposes ever since the beginning of the nineties, received also important orders from the Norsk Hydro for the installations in question. We propose to give a brief description of the plant supplied up to the present.

The first important contract was in 1914, when an eleventh generator was installed at the Vemork generating station. Whilst each of the existing ten units were designed as double generators for 17,000 KVA at 250 rpm. and 10,000/11,000 volts, the Oerlikon Co. built the new machine, for the same output, speed and pressure, with only one stator and rotor. This generator too, was for coupling to a horizontal water turbine. The installation of this plant was followed by that of two further three-phase generators for 6270 KVA at 9,000/11,000 volts, 250 rpm. at the Saaheim power station; one of the machines was erected in the generating station itself, whilst the other one was placed in a shaft in the mountain and was used for the general light and power supply of the Works at Rjukan.

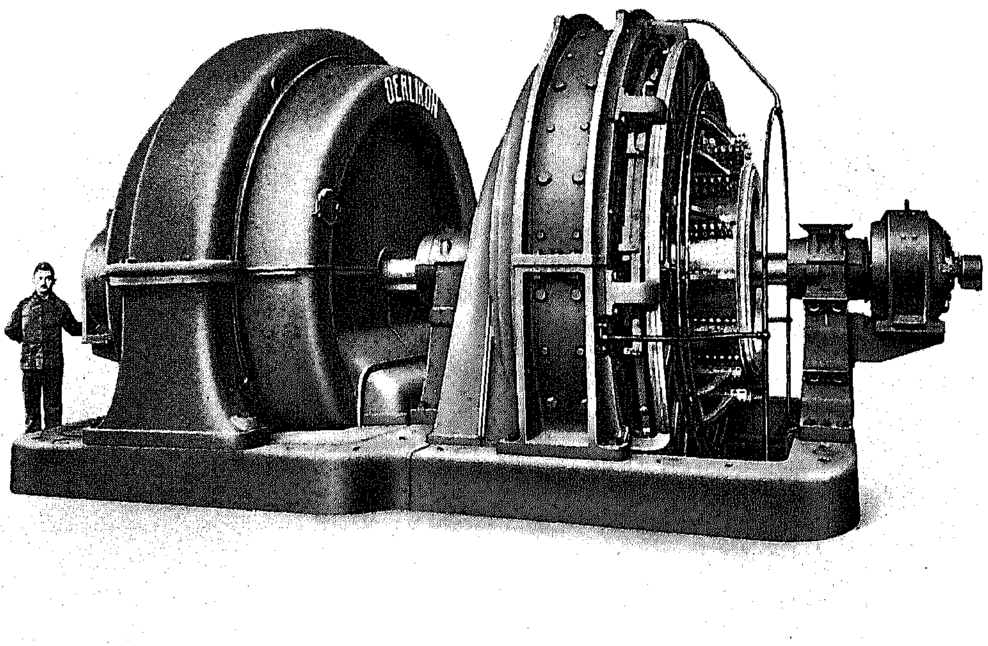
The following year the Oerlikon Company received an order from the Norsk Hydro for 12 high speed three-phase slipring motors, each for 250 HP, 3000 rpm., with regulating starter, for a permanent speed reduction down to 2000 rpm., with brushes resting permanently on the sliprings, and also for 13 three-phase slipring motors each for 225 HP. at 1500 rpm. These motors are direct coupled to gas blowers, which deal with gases at a temperature up to 240° C (465° F).

Six further three-phase slipring motors, each designed for 350 HP. at 3000 rpm., with short-circuiting device, serve for driving directly the compressors. All 31 motors are wound for 500 volts, 50 cycles; they are intended for continuous service day and night and are built in such a way that the fresh air is drawn in from the outside through a pipe and the warm air is delivered into the machine room.

The Oerlikon Company supplied in 1916 for a further extension of the installation at the Saaheim power station a turbo set consisting of a steam turbine for a steam pressure of 12 Kg/cm^2 (170 lbs/sq. in.) and a steam temperature of 300-320° C (570-610° F), direct coupled to a turbo-generator, which had to develop at 9500 volts an output of 4,000 KW.

Eleven years later, an order was placed with the Oerlikon Company for a twelfth generator for the last extension at the Vemork power station; this generator was for an output of 18 350 KVA at 600 rpm. and 10,000-11,000 volts. Up to that time the Norsk Hydro had only horizontal machines in operation. The lack of space at the power station and also the excellent results obtained in the meantime with vertical water driven units, led the Norsk Hydro to give preference to the vertical arrangement for this last unit. As the generator in question was a high speed machine, the fact that the rotor design of high speed generators of the Oerlikon Co.

embodies a device for fastening the poles by means of claws in round holes affording the maximum security, was a factor which influenced, to a considerable extent, the placing of the order with them. Owing to the generator having to work on arc furnaces, a type of plant liable to give rise to high frequency currents in the neutral conductors, the stator winding which is arranged in open slots was very amply dimensioned and a specially fine division of the neutral conductor was adopted with careful twisting of the individual layers. The winding had also to satisfy special conditions as regards ability to withstand short-circuits and in the matter of insulation.

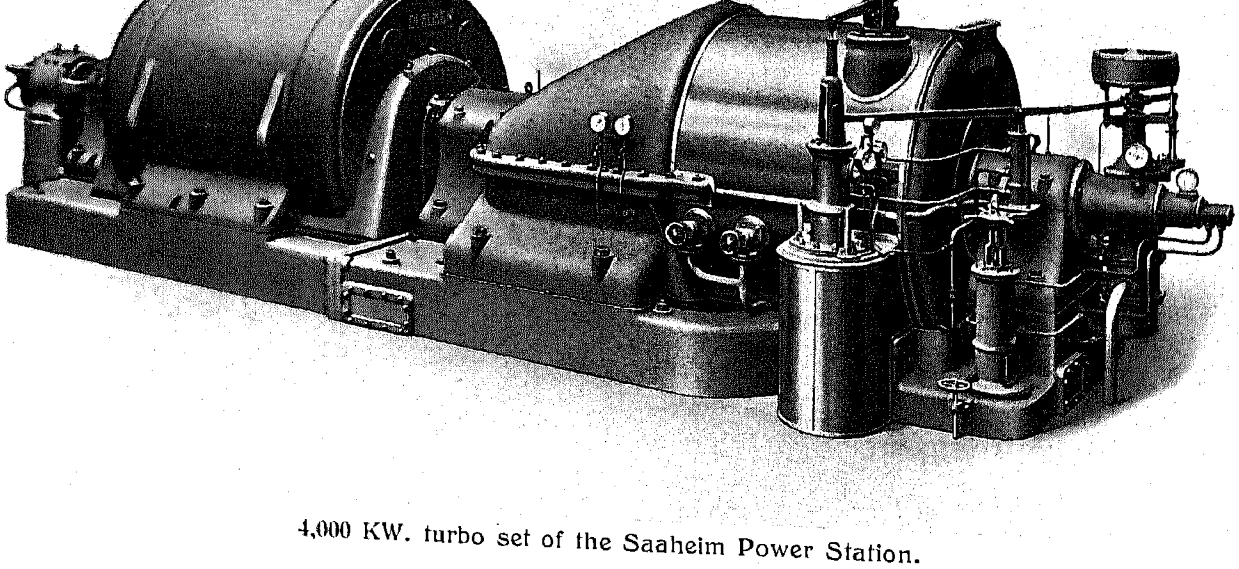


4,000 KW. motor generator set of the Notodden Salpetre Works.

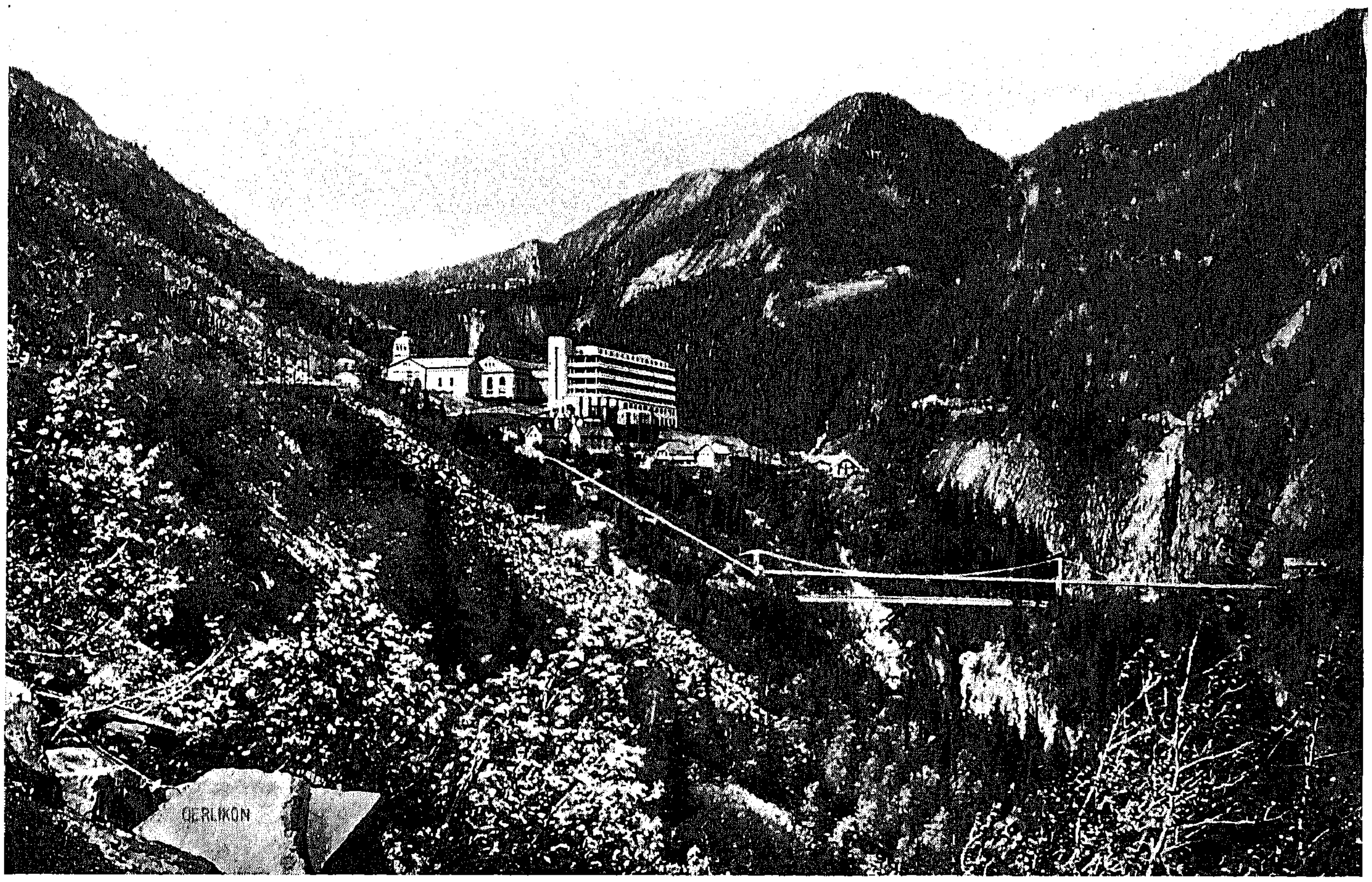
The erection of this vertical generator marked the end, once and for all, of the extensions on this power development and, consequently, of the production of alternating current by the Norsk Hydro.

Endeavours had been made for a long time in Europe, to devise a new method of producing nitrogen in place of the Birkeland-Eyde process, which was not too economical, such as would permit of a better utilisation of the electrical energy and consequently of a more economical production of nitrogen. As a result, a new process was evolved — the so-called ammonia synthetic process — which is based on the researches of Haber, Claude, Fauser, Casale and others, where nitrogen and hydrogen are directly combined at a high pressure and the hydrogen can be obtained electrolytically by the decomposition of water. The new process necessitated a large supply of D. C. energy and, furthermore, entailed the conversion of the whole manufacturing equipment used for the old Birkeland-Eyde process.

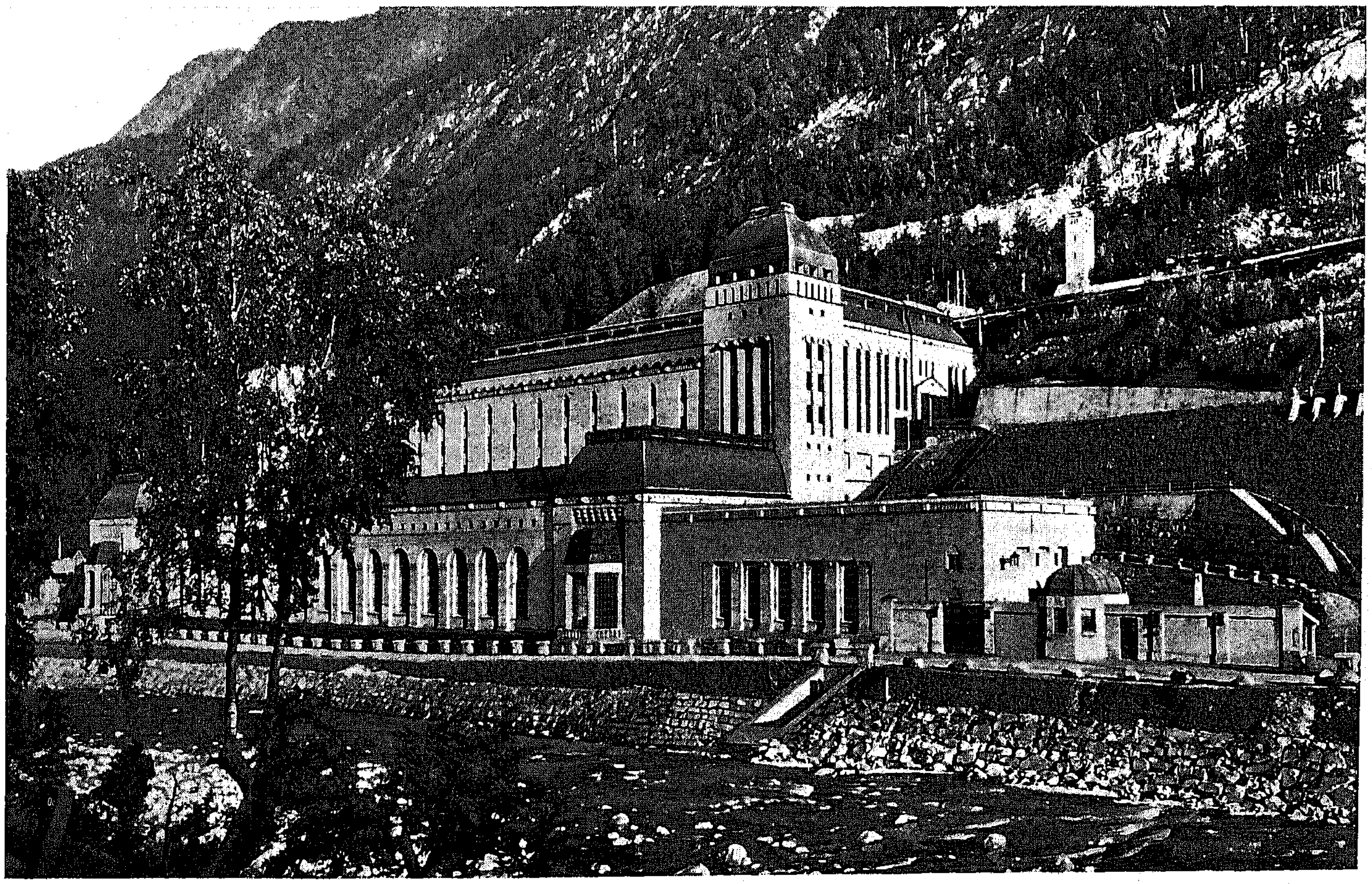
In order to elucidate all the questions connected with the new method, the Norsk Hydro erected in first instance at their Notodden Salpetre Works south of Rjukan a trial plant, where provision was made for 3 three-phase D. C. motor generator sets for the supply of the necessary D. C. energy. Very severe conditions were imposed by the client for this plant. In view of their long experience in the construction of D.C. machines for various electro-chemical purposes, the Oerlikon Company were entrusted with the supply of one of the motor generator sets, while the other two sets were ordered from two other leading firms.


4,000 KW. turbo set of the Saaheim Power Station.

This motor generator set, supplied in 1927, consists of a totally enclosed, three-phase synchronous motor with powerful damper windings, started directly from the

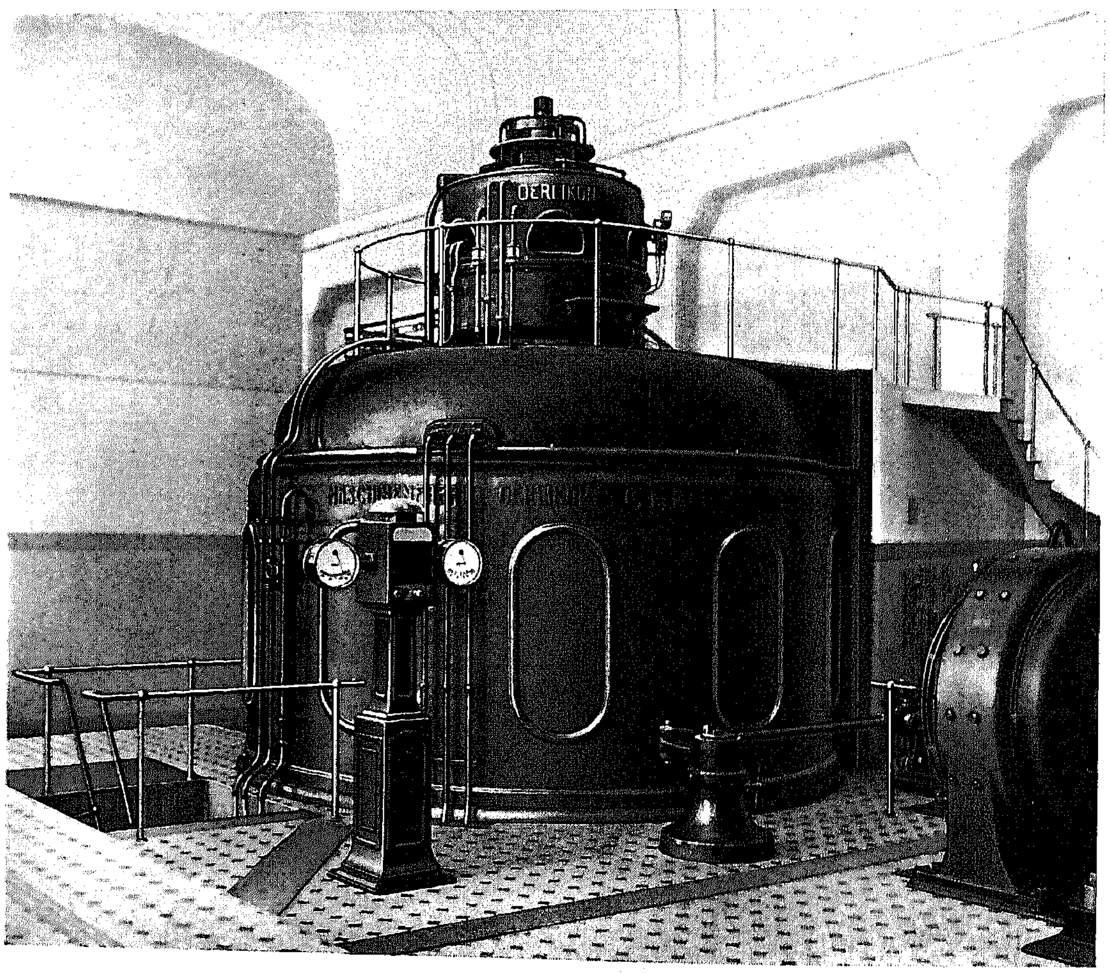


Vemork Power Station with electrolyser installation and bridge for the pipes for the hydrogen (in the foreground).


Saaheim Power Station.

9700 volt system by means of starting transformer and step switch, direct coupled to a D. C. shunt generator for 3500 KW, 700 volts, 5000 amps, 375 rpm. with separate excitation, interpoles and compensation windings, and with pressure regulation within the limits 500-725 volts, for continuous operation day and night. The D. C. machine must be capable of working in parallel, without any trouble, with the two other machines, on an electrolytic hydrogen battery. This set too has given the best results during service; it is characterised, on the one hand, by smooth running and by the small rushes of current it gives rise to on the A. C. side and, on the other hand, by good commutation on the D. C. side under all conditions of service.

On the basis of the results obtained with their trial plant, the Norsk Hydro decided, in 1927, to convert in stages the process of manufacture from the arc method to the ammonia synthetic process. As a result of exhaustive study of the economic side of the question, it was decided first of all, to replace the ten 18,000 HP. three-phase generators at the Vemork generating station, by ten sets comprising each 2 direct coupled D.C. generators for 6,000 KW. This meant that 20 new 6,000 KW. D.C. generators had to be built, the machines being arranged in groups of two generators each driven by an existing turbine. The direct current generated by these 10 sets is utilised in the electrolysers installed in the neighbourhood of the Vemork power station, and the hydrogen and oxygen produced are led from there in pipes to the works at Rjukan.



18,350 KVA three-phase generator at the Vemork Power Station.

The Oerlikon Company secured, in open competition with the leading European firms, 4 of the ten 12,000 KW. D.C. sets.

The 12 000 KW. D.C. sets are intended for a continuous 24-hour service throughout the whole year; they consist of 2 D.C. generators with one commutator and common middle bearing, and with an exciter for the separate excitation of the two machines.

Each of the 8 generators is designed for an output of 6,000 KW. at all pressures between 470 and 540 volts, the pressure during continuous service under normal conditions being about 500 volts.

The speed of 250 rpm. was imposed by the existing water turbines, and the runaway speed of 480 rpm. too. All the rotors were subjected to an overspeed test at the latter speed for 5 minutes at the Oerlikon Works.

In accordance with the usual present-day practice, insofar as large units are concerned, the generators in question are of the totally enclosed design with open commutator. The necessary cooling air is, in the case of each set, drawn from the outside and the warm air is led back into the open, use being made as far as possible of the existing air ducts. Special attention has been paid to the energetic ventilation of all the heat producing parts of the machines.

The large capacity of these generators, necessitated very large dimensions and weights of rotor. The rotors were completely erected at the Works and transported to site in one piece. In order to permit of the easy exchange of the armatures and to be able to dispense with the provision of more than one spare rotor, both rotors of the set were made identical. The 8 generators, including the spare rotor have a total weight of more than 700 tons. The nine rotors which represented by far the heaviest parts, their weight being 36 tons, were transported on special platform trucks without any trouble. The rotors were dispatched partly on direct railway trucks via Sassnitz-Trelleborg to Rjukan and partly via Hamburg and the sea route to Oslo, as in the winter 1928/29 the ferry section Sassnitz-Trelleborg was blocked by ice for a considerable period. All the transports had further to be conveyed, north of Oslo, on a ferry, across the Tinn Lake; this necessitated special precautions when running the long platform trucks on and off the ferry, in view of the very fluctuating level of the lake. Fifty trucks were required in all for the transport of these

4 sets. The erection at the Vemork power station had to be carried out under very difficult conditions and, furthermore, it had to be completed in the shortest time, as this operation meant, in the case of each unit, the putting out of service of one set, the dismantling of the three-phase generator, the alteration of the foundations and the erection of the double D. C. set, with as short an interruption of service as possible.

All machines have been in operation for $1^1/_2$ years and have been working nearly continuously on the newly erected electrolyser batteries.

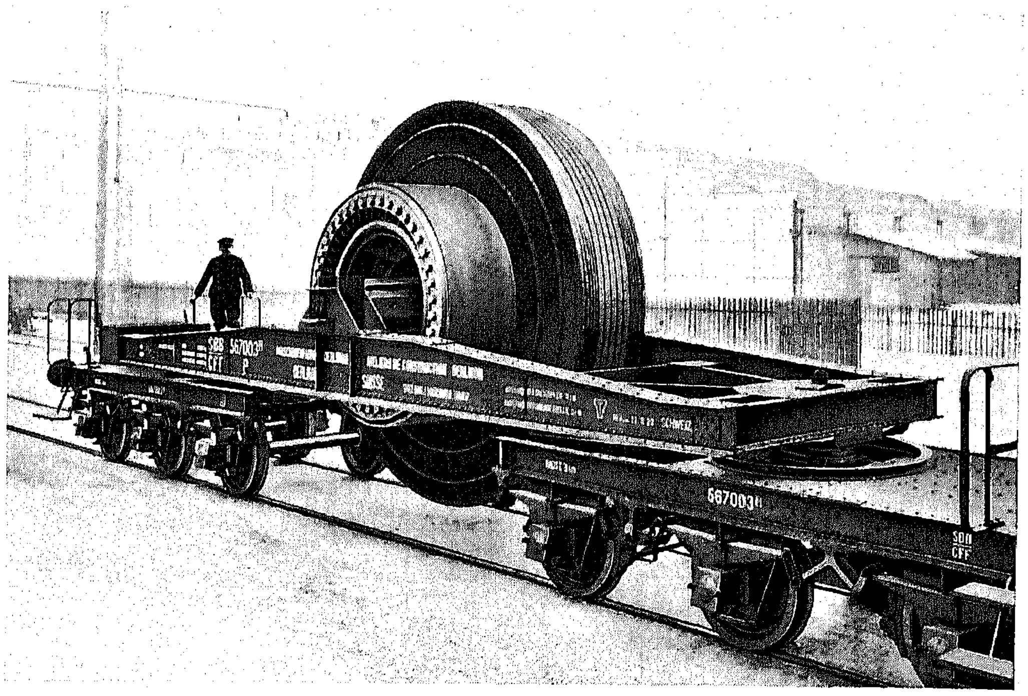
In conclusion, we propose to refer briefly to a number of motors, transformers and other electric material of interest supplied for the various works of the Norsk Hydro.

A large number of three-phase motors of different capacities, part of which are designed with double cage rotors, have been supplied for the absorbtion plant; these machines are of the totally enclosed type with jacket cooling and cable boxes. Some of the motors had to be specially protected against acid vapours, others had to be provided with explosion proof casing to withstand an explosion pressure of 12 atm. (170 lbs/sq. in.) as they were to be installed in rooms containing hydrogen vapours (oxyhydrogen gas). The Oerlikon Company have evolved for the latter explosion proof motors a new design with double jacket casing. This casing consists of the totally enclosed inner casing with the electrical parts of the motor and the outer casing; between the two, there is an intermediate air chamber through which the cooling air is driven by means of a fan. The inner casing is closed off, on the sides, by means of two cast steel shields. The casing is tested with water at a pressure of 12 atm. (170 lbs/sq. in.) and is capable not only of withstanding any explosion that may occur inside the motor, but also of preventing the propagation of an oxyhydrogen explosion to the outside.

In the case of the slipring motors, the sliprings are arranged in a special outer cast iron casing. The leads passing through the casing terminate in a cast iron cable box, which is arranged for taking armoured cable and is made gas-tight in relation to the outside. Motors of this design have been working for years without trouble in the Norsk Hydro installations.

Finally, mention can be made of two 600 KW electrode steam boilers supplied with the corresponding transformers; they are for generating 760 Kgs (1670 lbs) of steam per hour at a working pressure of 8 atm. (114 lbs/sq. in.) and are capable of withstanding a test pressure of 16 atm. (226 lbs/sq. in.). The quantity of steam generated is regulated by varying the feed water supply. The feed water pump is a high pressure turbo-pump for a head of 95 m. (310 ft.) and with a capacity of 1200 litres/min. (264 galls.). Many years' experience with installations of the kind has shown that the water in Norway is, as a rule, perfectly suitable, as regards electric conductivity, for the operation of electrode boilers.

As further material supplied, reference can be made to the portable welding sets which are of the single welder type; one of these is at the Rjukan Works and the other at the Heröen Works.



Rotor of a 6,000 KW generator with special platform truck.

ATELIERS DE CONSTRUCTION OERLIKON, OERLIKON

Three-phase Generators for the Oberhasli Power Supply Company.

The Oberhasli Power Supply Company have erected about 8 miles above Innertkirchen a generating station known as the Handeck Power Station for the utilisation of the initial head of the power development. This power station is equipped with four sets with a total capacity of 120,000 HP. Each set consists of a vertical three-phase generator for a continuous output of 28,000—32,000 KVA, 11,000 volts, 500 rpm., 50 cycles, and of a double nozzle Pelton turbine developing a normal output of 30,000 HP. under a head of 540 metres (1770 ft.). The turbine wheel is mounted overhung on the lower conical shaft extension of the generator.

All four generators were supplied by the Oerlikon Company. The general arrangement of the machine sets is such that the main part of the generator is on an intermediate floor of the power station and consequently the thrust bearing, the main exciter and the two auxiliary exciters alone project above the machine room floor (see view of machine room on page 637). The supporting frame of the lower guide bearing which rests in a recess of the circular bedplate forms a fixed partition between the generator and the turbine chamber, so that in the event of any defect occurring in the hydraulical part and of the turbine chamber being completely flooded, no water can penetrate into the generators. The upper supporting frame, which is in several parts, carries the thrust bearing and is dimensioned to take the whole weight of the rotating part amounting to about 90 tons. The latter can be raised from the generator shaft when dismantling the plant by means of lifting tackle after the two auxiliary exciters on the shaft have been removed. In order to keep within the prescribed maximum weight of 20 tons, the shaft was divided in the middle, and the two parts assembled by means of flanges.

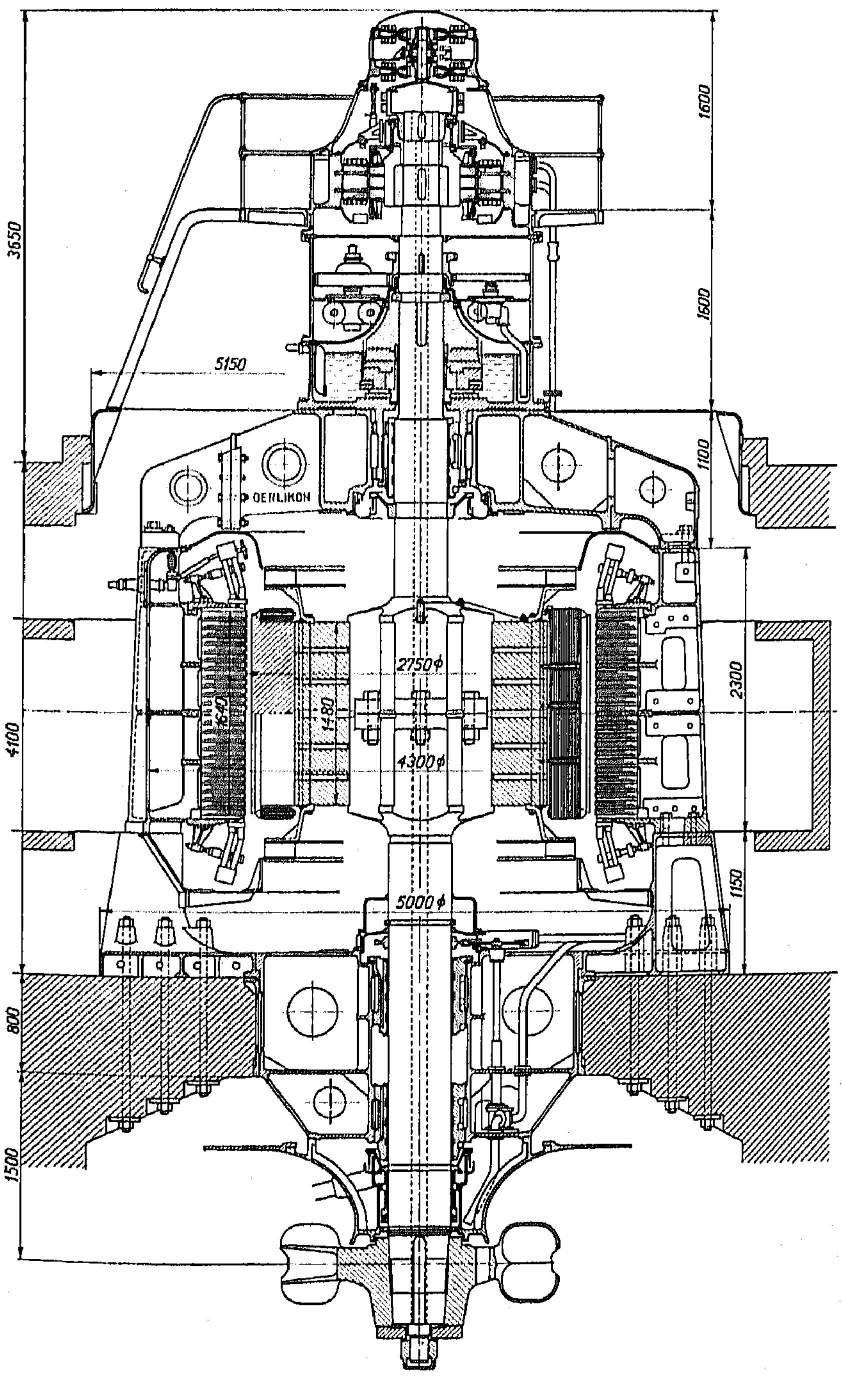
The rotor body consists of 12 massive forged pole cores of S.M. steel and six rotor rings of the same material, three rings being shrunk on either of the two hubs of the two shaft halves. The poles are secured to the rings by means of claws fitting in round holes, a special design adopted by the Oerlikon Company for many years.

The stator is in four parts and the winding is in the form of a lattice winding; the latter is built up of bars easily interchangeable and secured in such a way as to withstand effectively short circuits. The main exciter, as well as the two auxiliary exciters, are mounted above the thrust bearing. The auxiliary exciters permit of the rapid and stable regulation of the pressure and the current of the generator, this being done by varying the resistance in the shunt circuit of these exciters.

The protective equipment comprises, in the case of each generator, a maximum current time relay, a differential relay, an earth relay used in conjunction with a neutral point earthing resistance, and a maximum pressure relay. Provision is further made for a quick de-energising device by means of which it is possible to ensure the disappearance of the generator pressure in the shortest time.

Each generator is connected directly to the low tension winding of the corresponding 11/50 KV transformer without insertion of a switch. The power is likewise transmitted directly from the H.T. terminals, by means of a 50-60 KV cable 3.1 miles long and an overhead line 5 miles long, to the Innertkirchen out-door sub-station, where the switching is done on the HT. side, on to the 150 KV lines.

In order to check the guarantee figures given, tests regarding all guarantees were carried out at the Oerlikon Works, while the generator, complete with turbine wheel, was furthermore subjected to an eight day trial run.

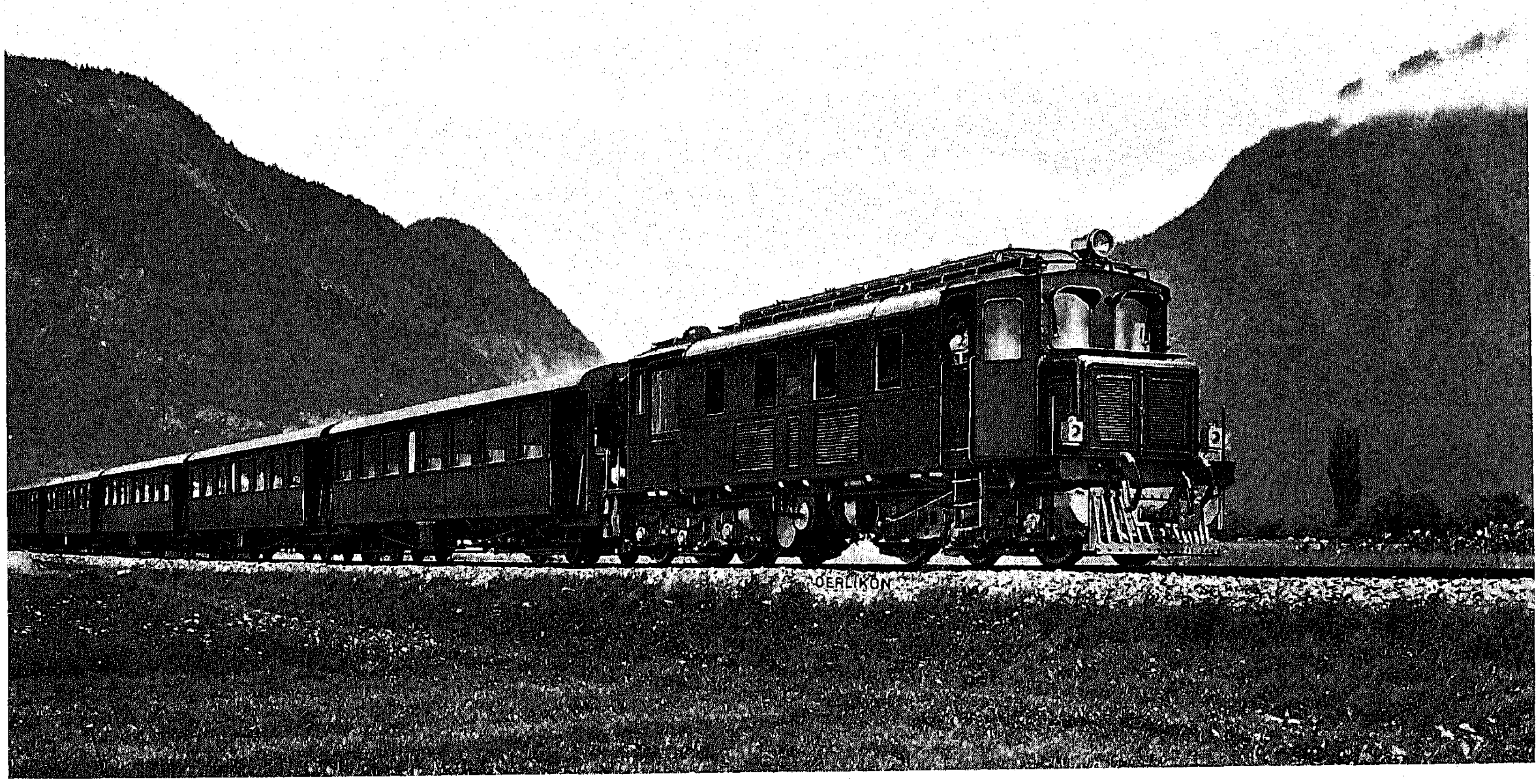


ATELIERS DE CONSTRUCTION OERLIKON, OERLIKON

BULLETIN OERLIKON

No. 123 — September 1931

Contents: Diesel-electric locomotives for Siam.
Internal outputs and currents in ordinary Scott-connected auto-transformers.
Notes and News Items: Method for measuring the arc pressure of mercury rectifiers.
Device for preventing the excess braking of railway vehicles.



155 ton trial train with one of the 450 HP. Diesel-electric locomotives for Siam, on the system of the Rhætian Railway.

Diesel-electric Locomotives for Siam. The Royal State Railways of Siam placed a contract last year for 19 Diesel-electric locomotives and motor coaches. The Frichs Locomotive and Machine Works of Aarhus and Messrs. Sulzer Bros., as main contractors, ordered the electrical equipment of the locomotives to be supplied by them from the Oerlikon Company. Six 900 HP. express locomotives and six 450 HP. locomotives will be put into service in Siam in the course of this year, while the remaining locomotives and motor coaches will reach Bangkok a little later.

Before the locomotives were delivered they had to undergo exhaustive acceptance tests. Daily trial runs, for instance, were carried out last July for two weeks with one of the six 450 HP. locomotives on the mountain section Landquart-Disentis of the Rhætian Railway; these tests took place without any trouble and they all gave very satisfactory results.

These locomotives are each equipped with a 450 HP. Sulzer-Diesel engine. In view of the tropical climate, the limited axle pressure of 11 tons, the small gauge of track of 1 metre (3.28 ft.) and the working programme (passenger service and shunting, and exceptionally express service too over a 2000 Km. (1220 miles) line without renewal of fuel, the locomotive was built as a "universal" locomotive and made of amply dimensioned and heavy design. The total weight of the locomotive amounts to about 60 tons.

With a supply of about 2.8 tons of fuel, the locomotives are capable of hauling an express train with a total weight of 260 tons at a speed of 50 Km/h (31 mph) over the 2000 Km line. Their maximum speed amounts to 60 Km/h (37.2 mph), as in the case of the other express locomotives of this railway; the tractive effort at starting can be increased to 11,000 Kgs (22,000 lbs).

Internal Outputs and Currents in Ordinary Scott-connected Auto-transformers [1].

(Two-phase system with four conductors).

We propose to study here the conversion of three-phase energy into two-phase energy at the same frequency, and vice-versa, by means of an ordinary Scott-connected auto-transformer, such as represented diagrammatically in Fig. 1. We shall take the case of a two-phase system with four conductors with separate phases; the two phases have a common point M.

In order that this article should serve a practical purpose, we shall make use of curves as the latter are clearer than formulae and make it possible to ascertain at a glance the internal output of each of the two single-phase transformers forming the Scott transformer set. The internal output which fixes both the design and the value of the magnetic circuit, is expressed in % of the external output of the set.

Let us adopt the following designations:

Index 2 Two-phase,
„ 3 Three-phase quantities.
J_2 Two-phase current,
J_3 Three-phase current, in amps.
V_2 Two-phase pressure,
V_3 Three-phase pressure, in volts.
P External capacity or external output of the Scott transformer set, in KVA.

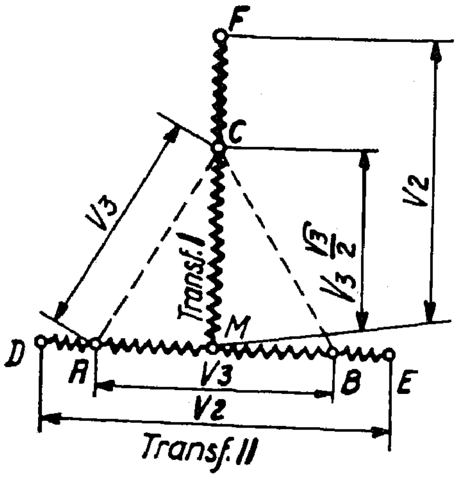


Fig. 1.

P′ and P″ = Internal capacity (in KVA) of the transformers I and II, or capacity of an equivalent ordinary single-phase transformer with two separate windings (primary and secondary winding) and with same actual transformed output (standardised transformers, as the case may be).

Internal output = $\frac{\text{Total output which is produced in the windings}}{2}$

= Output of the magnetic circuit.

[1] For particulars regarding other similar Scott connections see "Le couplage Scott et les montages similaires" by H. de Pistoye in the R. G. E., Vol. XXV, No. 1.

Let us write: $P' = p'\,P$ $\quad J' = i'\,J_3$
$P'' = p''\,P$ $\quad J'' = i''\,J_3$

Data given: P V_2 V_3, from which we can derive J_2, J_3

Unknown quantities: P' P'' J' J'' or according to the relations laid down above p' p'' i' i''.

The quantity $\beta = \frac{V_2}{V_3} = \frac{\text{two-phase pressure}}{\text{three-phase pressure}}$ will be taken as a parameter.

β will be made to vary from o to + infinity, so that we shall obtain every possible case. As the two-phase and three-phase outputs are the same, we can write:

$$\sqrt{3}\,V_3\,J_3 = 2\,V_2\,J_2 \qquad J_2 = \frac{\sqrt{3}}{2\beta}\,J_3 \qquad V_2 = \beta\,V_3$$

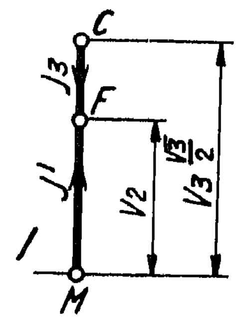
Transformer I.

The currents J_2 and J_3 have a phase displacement in relation to each other of 180°. We have three different cases, according to the position of the point F.

I) $\beta < \frac{\sqrt{3}}{2}$ (Fig. 2).

The point F is between M and C.

Fig. 2.



Winding FM:
- Current: $J' = J_2 - J_3 = J_3\left(\frac{\sqrt{3}}{2\beta} - 1\right)$
- Pressure: $V_2 = \beta V_3$
- Transformed output, in KVA: $V_3 J_3 \left(\frac{\sqrt{3}}{2} - \beta\right) 10^{-3}$

If the currents J_2 and J_3 are at an angle of 180°, one of the windings, FM, for instance, acts as the primary winding of a transformer with two separate coils, FC being the secondary winding. As the primary and secondary ampere-turns are equal, it follows that this must also be the case for the outputs transformed in the windings FM and FC. We thus have:

$$P' = V_3 J_3 \left(\frac{\sqrt{3}}{2} - \beta\right) 10^{-3} = V_3 J_3 \sqrt{3}\, 10^{-3} \cdot \left(\frac{1}{2} - \frac{\beta}{\sqrt{3}}\right)$$

$$= P\left(\frac{1}{2} - \frac{\beta}{\sqrt{3}}\right) = P\,p'$$

$$p' = \frac{1}{2} - \frac{\beta}{\sqrt{3}}$$

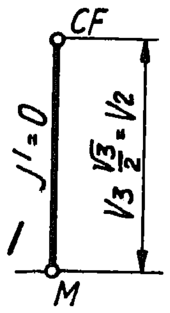


Fig. 3.

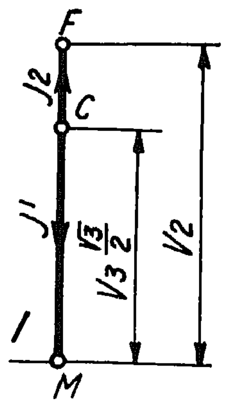


Fig. 4.

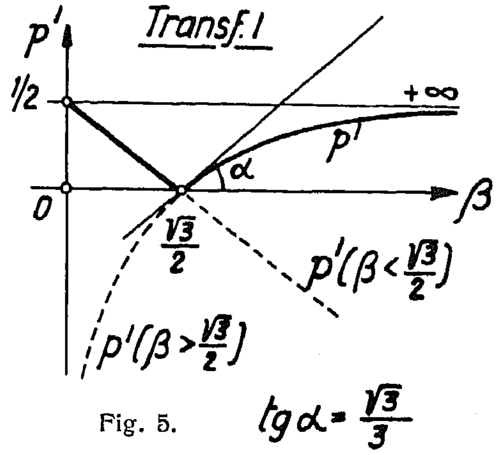


Fig. 5.

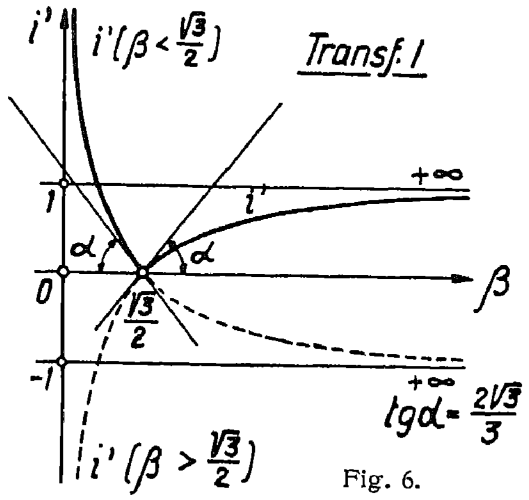


Fig. 6.

In a rectangular system of co-ordinates ($\beta\, p'$), the latter equation represents a straight line passing through the points $\left(o, \frac{1}{2}\right)$ and $\left(\frac{\sqrt{3}}{2}, o\right)$. Only the portion of this line between $\beta = o$ and $\beta = \frac{\sqrt{3}}{2}$ is utilised in practice (Fig. 5).

$$J' = J_3\left(\frac{\sqrt{3}}{2\beta} - 1\right) = J_3\, i'$$

$$\underline{i' = \frac{\sqrt{3}}{2\beta} - 1}$$

This equation represents an equilateral hyperbola, of which the centre point is (o, −1), and the asymptotic equations are $\beta = o$, $i' = -1$ (Fig. 6). The physically useful range is $\beta = o$ to $\frac{\sqrt{3}}{2}$.

II) $\underline{\beta = \frac{\sqrt{3}}{2}}$ (Fig. 3). The point F coincides with C.

Winding CF-M		
	Current	$J' = J_2 - J_3 = o$
	Pressure	$V_2 = V_3 \frac{\sqrt{3}}{2}$
	Transformed output	$= o$

$$P' = p'P = o \qquad J' = i'\, J_3 = o$$

As P and J_3 are different from zero, we have:

$$\underline{p' = o} \qquad \underline{i' = o}$$

The transformer I is superfluous and can be dispensed with. There remains only transformer II for forming the Scott transformer set.

III) $\underline{\beta > \frac{\sqrt{3}}{2}}$ (Fig. 4). The outputs transformed in the windings CM and CF are the same, as was the case for $\beta < \frac{\sqrt{3}}{2}$.

Winding CM		
	Current	$J' = J_3 - J_2 = J_3\left(1 - \frac{\sqrt{3}}{2\beta}\right)$
	Pressure	$V_3 \frac{\sqrt{3}}{2}$
	Transformed output, in KVA.	$V_3 J_3 \sqrt{3}\left(\frac{1}{2} - \frac{\sqrt{3}}{4\beta}\right) 10^{-3}$

$$P' = P\left(\frac{1}{2} - \frac{\sqrt{3}}{4\beta}\right) = P p'$$

$$\underline{p' = \frac{1}{2} - \frac{\sqrt{3}}{4\beta}}$$

The equation represents an equilateral hyperbola, with $\left(o, \frac{1}{2}\right)$ as co-ordinates of centre point and $\beta = o$ and $p' = \frac{1}{2}$ as asymptotic equations. The physically useful range is $\beta = \frac{\sqrt{3}}{2}$ to + infinity (Fig. 5).

$$J' = J_3\left(1 - \frac{\sqrt{3}}{2\beta}\right) = i'\, J_3$$

$$\underline{i' = 1 - \frac{\sqrt{3}}{2\beta}}$$

This is an equilateral hyperbola (Fig. 6) with (o, 1) as co-ordinates of centre point and $\beta = o$, $i' = +1$ as asymptotic equations. The physically useful range is $\beta = \frac{\sqrt{3}}{2}$ to + infinity.

Transformer II.

We have here, as above, three cases:

I) $\underline{\beta < 1}$ (Fig. 7). The points D, E, are between A and B. It must be noted that the currents J_2 and J_3 are at an angle of 150° and that the current J'' resulting from their superposition in the winding DME is equal to their geometrical sum. Fig. 8 gives us:

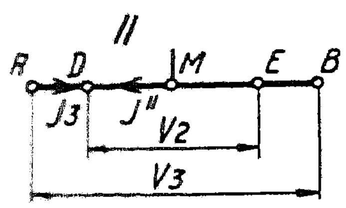


Fig. 7.

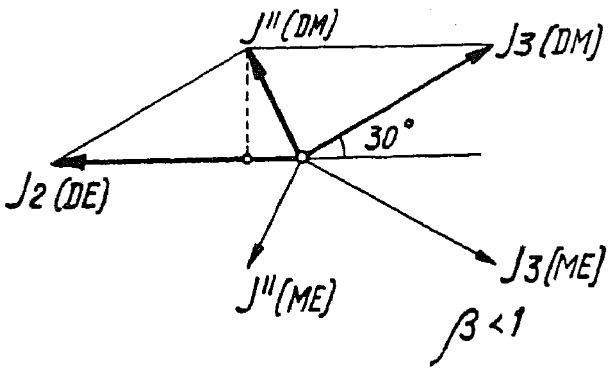


Fig. 8.

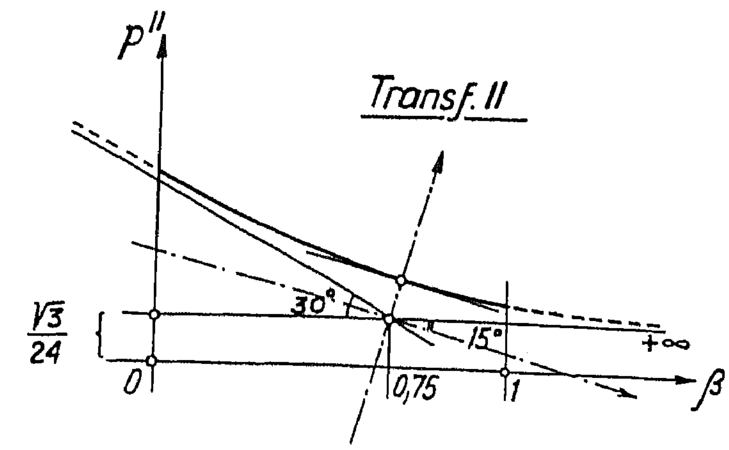


Fig. 9.

$$\vec{J}'' = \vec{J}_2 + \vec{J}_3$$

$$J''^2 = (J_2 - J_3 \cos 30^0)^2 + (J_3 \sin 30^0)^2$$

$$= \left[J_3 \frac{\sqrt{3}}{2}\left(\frac{1}{\beta} - 1\right)\right]^2 + \left[\frac{J_3}{2}\right]^2$$

$$J'' = \sqrt{\frac{3}{4} J_3^2 \left(\frac{1}{\beta} - 1\right)^2 + \frac{1}{4} J_3^2} = \frac{J_3}{2\beta}\sqrt{4\beta^2 - 6\beta + 3}$$

Winding DME	Current	$J'' = \frac{J_3}{2\beta}\sqrt{4\beta^2-6\beta+3}$
	Pressure	$V_2 = \beta V_3$
	Transformed output, in KVA.	$\frac{J_3 V_3}{2}\sqrt{4\beta^2-6\beta+3} \cdot 10^{-3}$
Winding AD-EB	Current	J_3
	Pressure	$V_3 - V_2 = V_3(1-\beta)$
	Transformed output, in KVA.	$V_3 J_3 (1-\beta)\, 10^{-3}$

$$P'' = \frac{1}{2}\left[\frac{V_3 J_3}{2}\sqrt{4\beta^2-6\beta+3} \cdot 10^{-3} + V_3 J_3 (1-\beta)\, 10^{-3}\right]$$

$$= \frac{1}{2\sqrt{3}}\left[\frac{1}{2}\sqrt{4\beta^2-6\beta+3} - \beta + 1\right] P = p'' P$$

$$p'' = \frac{1}{2\sqrt{3}}\left[\frac{1}{2}\sqrt{4\beta^2-6\beta+3} - \beta + 1\right]$$

Special case $\beta = 1$, $p'' = \frac{1}{4\sqrt{3}}$. The equation p'' = function of β represents the upper branch of a hyperbola with $\left(\frac{3}{4}, \frac{\sqrt{3}}{24}\right)$ as coordinates of centre point and with $p'' = \frac{\sqrt{3}}{24}$ and $p'' = -\frac{\sqrt{3}}{3}\beta + \frac{7\sqrt{3}}{24}$ as asymptotic equations. The physically useful range is β = o to 1 (Fig. 9).

$$J'' = \frac{1}{2\beta}\sqrt{4\beta^2-6\beta+3}\; J_3 = i'' J_3$$

$$i'' = \frac{1}{2\beta}\sqrt{4\beta^2-6\beta+3}$$

Special case $\beta = 1$, $i'' = \frac{1}{2}$.

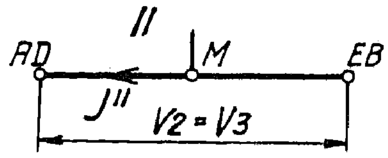


Fig. 10.

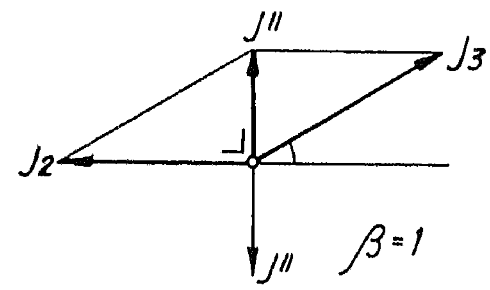


Fig. 11.

II) $\beta = 1$ (Fig. 10, 11). $J_2 = J_3 \frac{\sqrt{3}}{2}$, $V_2 = V_3$

Winding ADMEB	Current	$J'' = J_3 \sin 30^0 = \frac{1}{2} J_3$
	Pressure	$V_2 = V_3$
	Transformed output, in KVA.	$\frac{V_3 J_3}{2} 10^{-3}$

$$P'' = \frac{1}{2}\frac{V_3 J_3}{2} 10^{-3} = \frac{1}{4\sqrt{3}} P = p'' P$$

$$p'' = \frac{1}{4\sqrt{3}}$$

$$i'' = \frac{1}{2}$$

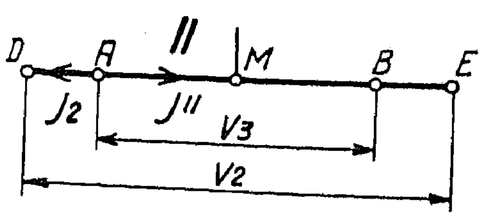


Fig. 12.

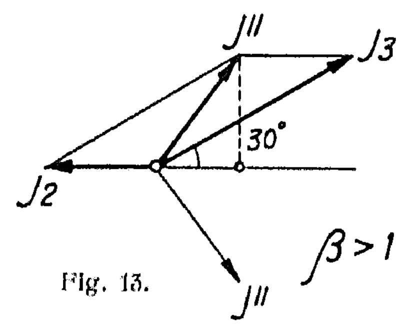


Fig. 13.

III) $\beta > 1$ (Figs. 12 and 13). The points A, B are between D and E.

Winding DA-BE	Current	$J_2 = \frac{\sqrt{3}}{2\beta} J_3$
	Pressure	$V_2 - V_3 = V_3(\beta - 1)$
	Transformed output, in KVA.	$\frac{V_3 J_3 \sqrt{3}}{2\beta}(\beta - 1)\, 10^{-3}$

Winding AMB

- Current (see Fig. 13): $\vec{J}'' = \vec{J}_2 + \vec{J}_3$

$$J'' = \sqrt{(J_3 \cos 30^0 - J_2)^2 + (J_3 \sin 30^0)^2} = \frac{J_3}{2\beta}\sqrt{4\beta^2 - 6\beta + 3}$$

- Pressure: V_3
- Transformed output, in KVA: $\frac{V_3 J_3}{2\beta}\sqrt{4\beta^2-6\beta+3}\cdot 10^{-3}$

$$P'' = \frac{1}{2}\left[\frac{V_3 J_3 \sqrt{3}}{2\beta}(\beta-1)\,10^{-3} + \frac{V_3 J_3}{2\beta}\sqrt{4\beta^2-6\beta+3}\cdot 10^{-3}\right]$$

$$= \frac{P}{4\beta}\left[\frac{1}{\sqrt{3}}\sqrt{4\beta^2-6\beta+3} + \beta - 1\right] = P p''$$

$$p'' = \frac{1}{4\beta}\left[\frac{1}{\sqrt{3}}\sqrt{4\beta^2-6\beta+3} + \beta - 1\right]$$

Special case $\beta = 1$, $p'' = \frac{1}{4\sqrt{3}}$. The general shape of this curve for $\beta > o$ is as shown in Fig. 15. One asymptote

$$p'' = \frac{1}{4} + \frac{1}{2\sqrt{3}}$$

We see that i″ is always expressed by the same formula and that the value β is always between o and + infinity.

$$i'' = \frac{1}{2\beta}\sqrt{4\beta^2-6\beta+3}$$

Table.

β	Transf. I p'	Transf. I i'	Transf. II p''	Transf. II i''
(formulas, β from 0 to $\frac{\sqrt{3}}{2}$)	$p' = \frac{1}{2} - \frac{\beta}{\sqrt{3}}$	$i' = \frac{\sqrt{3}}{2\beta} - 1$	$p'' = \frac{1}{2\sqrt{3}}\left[\frac{1}{2}\sqrt{4\beta^2-6\beta+3} - \beta + 1\right]$	$i'' = \frac{1}{2\beta}\sqrt{4\beta^2-6\beta+3}$
0	0.5	+∞	0.538	+∞
0.2	0.385	3.330	0.433	3.500
0.4	0.269	1.165	0.334	1.390
0.5				1
0.6	0.154	0.440	0.248	0.763
0.8	0.038	0.080	0.184	0.544
$\frac{\sqrt{3}}{2} = 0{,}866$	0	$\frac{di'}{d\beta} = -\frac{2\sqrt{3}}{3}$ 0		
	$\frac{dp'}{d\beta} = \frac{\sqrt{3}}{3}$ 0	$\frac{di'}{d\beta} = +\frac{2\sqrt{3}}{3}$ 0		
1	0.067	0.134	$\frac{dp''}{d\beta} = -\frac{1}{4\sqrt{3}}$ 0.145 / $\frac{dp''}{d\beta} = +\frac{1}{4}$ 0.145	$\frac{di''}{d\beta} = 0$ 0.5
(formulas, β above $\frac{\sqrt{3}}{2}$)	$p' = \frac{1}{2} - \frac{\sqrt{3}}{4\beta}$	$i' = 1 - \frac{\sqrt{3}}{2\beta}$	$p'' = \frac{1}{4\beta}\left[\frac{1}{\sqrt{3}}\sqrt{4\beta^2-6\beta+3} + \beta - 1\right]$	
1.2	0.139	0.278	0.192	0.520
1.4	0.191	0.381	0.233	0.558
1.6	0.229	0.459	0.266	0.597
$\sqrt{3}$	0.250	0.500		
1.8			0.293	0.631
2	0.284	0.567	0.317	0.662
2.5	0.327	0.654	0.358	0.722
3	0.356	0.711	0.387	0.763
4	0.392	0.784	0.424	0.819
+∞	0.5	1	0.538	1

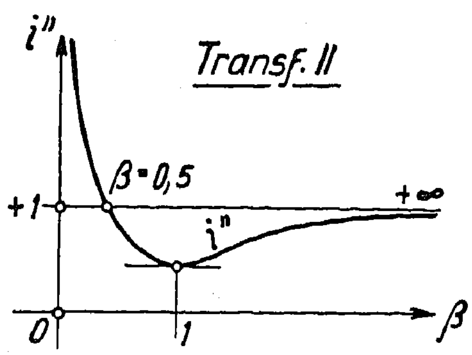


Fig. 14.

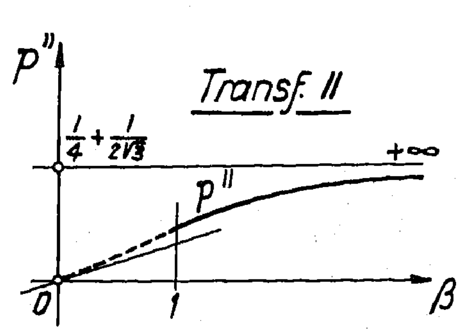


Fig. 15.

The curve represented by this equation is a branch of a curve of 4th order (Fig. 14). We see that in the physically useful range $\beta = o$ to + infinity, the curve has two asymp-

notes $\beta = 0$ and $i'' = 1$ and a minimum $i'' = \frac{1}{2}$ for $\beta = 1$.

The results arrived at have been grouped together in the accompanying table and in the curves in Figs. 16 and 17.

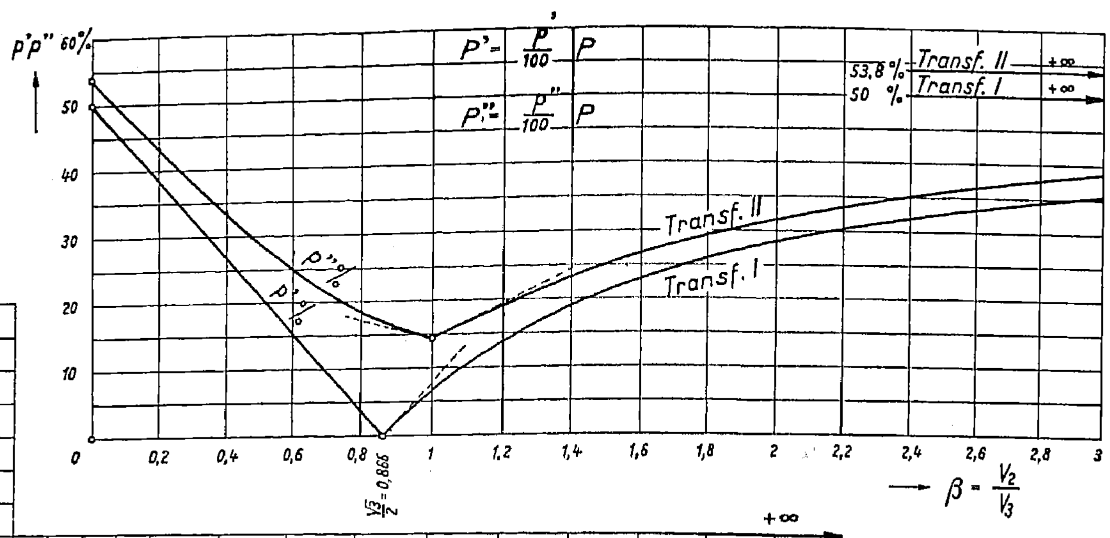


Fig. 17.

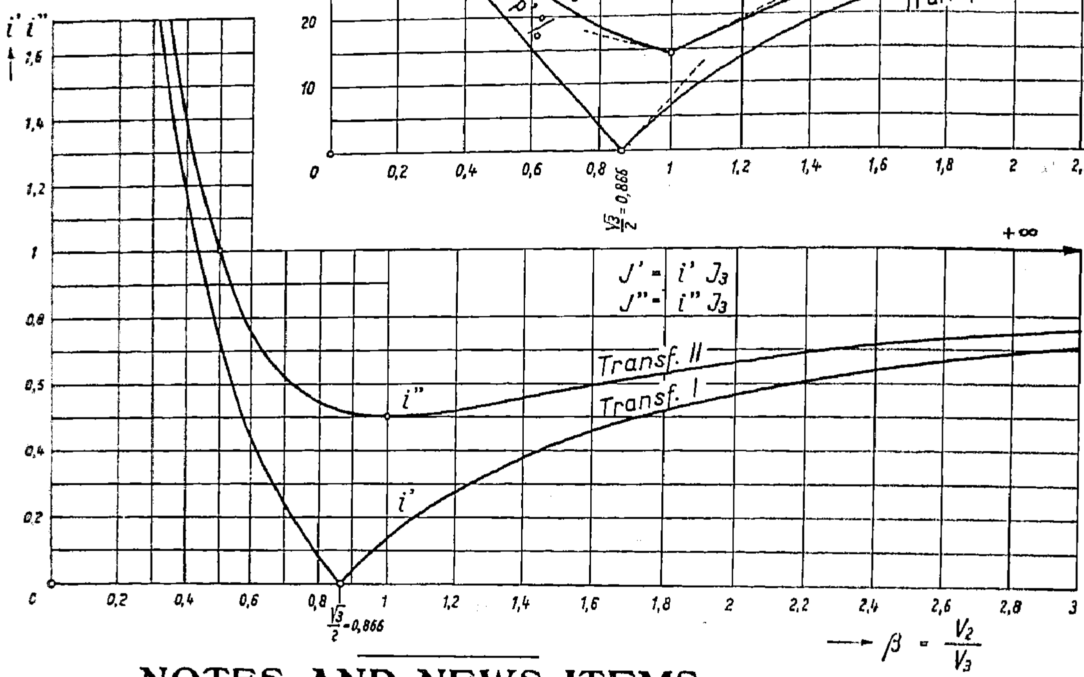


Fig. 16.

NOTES AND NEWS ITEMS.

Method for Measuring the Arc Pressure of Mercury Rectifiers. The more mercury rectifiers are used for low working pressures, the more important it is to keep the arc pressure low, as the latter determines primarily the losses. It is, however, indispensable to have a reliable method of measurement for studying the different factors that influence the arc pressure. If direct current is applied to the anode of a mercury rectifier, the arc pressure can be directly read on a voltmeter. This method gives, however, only very rough indications, as during normal service the pressure varies with the time, owing to the alterations that take place in the temperature and in the ionization along the path of the arc.

Various methods have been devised to measure the arc pressure while the mercury rectifier is in service[1]); these methods are, however, in most cases unreliable. The simplest of these consists in determining the arc output by means of a wattmeter as shown in Fig. 1, while the D. C. component of the anode current is measured by a moving coil ammeter. The arc pressure is then derived from the following relation:

$U_b = \frac{P}{I_g}$ where P is the output and I_g the mean value of the arc current. In the case of six-phase rectifiers, however, the readings are, in most cases, subject to very considerable errors. When the number of phases is smaller, the results agree well with those of other methods of measurement.

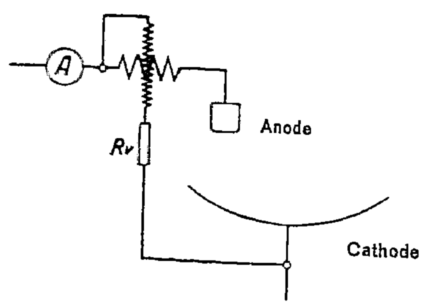


Fig. 1.

[1]) See for instance, K. E. Muller, "Mercury Rectifiers", Vol. 1, p. 60.

Another method consists in measuring the phase pressure and the pressure between anode and cathode with a hot wire voltmeter. It is, however, necessary, in such a case, in order to be able to measure the arc pressure, to know the duration of the arc. Efficiency measurements with wattmeters, on the primary side of the transformer, further necessitate an accurate knowledge of the transformer losses. It is also possible to obtain a few data for the determination of the arc pressure, by measuring the heat led away by the cooling water of the mercury rectifier.

In order to determine the exact mode of variation of the pressure with the time, it is absolutely necessary to take oscillographs. There is, however, this difficulty in doing so that during the time of interruption between anode and cathode, the pressure amounts to the whole phase pressure plus the working pressure. The curves obtained, then, for the arc pressure are as shown in Fig. 2. The degree of sensitiveness is in such a case very small, as one volt corresponds to a deflection of only 0.02 mm. Small variations

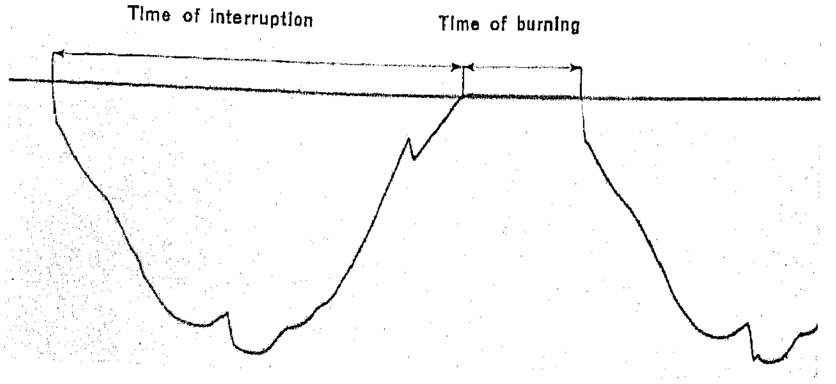


Fig. 2. Pressure between anode and cathode of a 6-phase mercury rectifier at 500 volts working pressure.

cannot therefore be observed in this way. In order to be able to utilise the whole available width of the strip for the arc pressure, the Oerlikon Company use an apparatus such as represented in Fig. 3.

The anode circuit of a triode valve comprises only the anode battery with oscillograph coil in series. The grid circuit consists of the arc to be measured, with the grid battery in series. The latter battery serves for making the necessary adjustments to suit the characteristic of the valve; it is, as a rule, chosen for a pressure of 30/40 volts, so that it should also be suitable for calibration purposes. The measurements are carried out as follows:—

The change-over switch U is set in the position 1, while the sliding contact of the balancing resistance is in A. During the period of interruption of the anode of the mercury rectifier, the anode is negative in relation to the cathode. The pressure of the grid battery acts in the same direction, so that the grid is strongly negative in relation to the filament, and stops the current in the anode circuit (oscillograph). As soon, however, as the anode of the mercury rectifier becomes positive and lets the arc pass, the arc pressure acts in opposite direction to the grid battery. The potential of the grid is no longer so highly negative in relation to the filament and permits of the passage of a current through the oscillograph coil corresponding to the arc pressure, until the anode becomes negative once more. After an oscillogram has been taken of this process, the change-over switch U is set in position 2, and the negative grid pressure is reduced by a given value by adjusting the balancing resistance, this pressure being measured with the voltmeter V, and an oscillogram is taken of this calibration pressure too.

Fig. 4, which represents the arc pressure of Fig. 2, was obtained by this method; the units can, now, be very clearly seen. The Oerlikon Company have taken a number of such oscillograms which have enabled them to build even large rectifiers with an arc pressure having only a moderate value.

Various secondary phenomena have, however, been encountered which are not yet sufficiently explained.

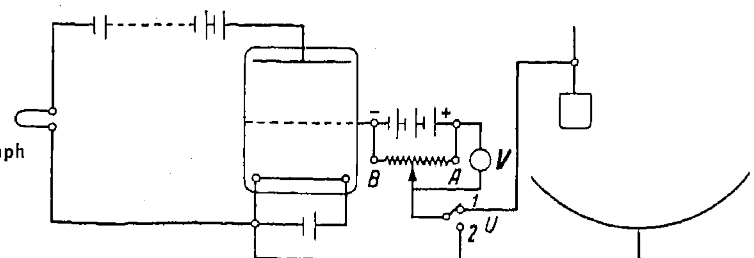


Fig. 3.

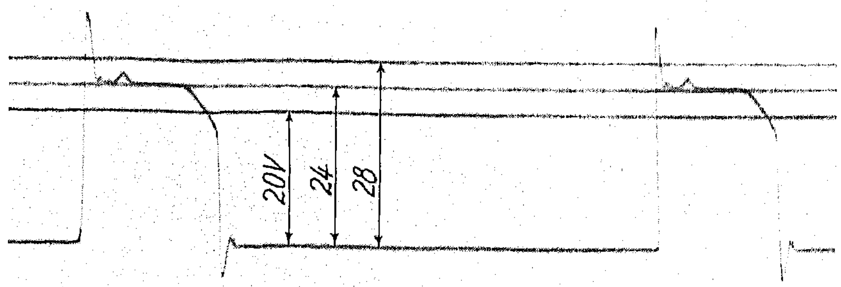


Fig. 4. Arc pressure of a 6-phase mercury rectifier with three calibration pressures.

Device for Preventing the Excess Braking of Railway Vehicles fitted with Mechanical Brake Operated by Brake Solenoid. (Patent applied for). The method of braking railway vehicles where use is made of brake solenoids acting on the brake rigging of mechanical brakes, has been known for a number of years. As a rule, the trailer coaches alone are equipped with brake solenoids, in which case their excitation coil is generally energised by the short-circuit current of the traction motors working as generators during braking. The tractive effort of the brake solenoid is usually calculated in such a way that, when acting on the brake rigging, it can deal with about 85 % of the dead weight of the vehicle in question.

The winding of the brake solenoid is, as a rule, dimensioned in such a manner that this braking effect is obtained with a current such as the motors of the corresponding motor-coach supply, once the conditions of equilibrium have been reached, when working with short-circuit connection on down-grade runs, on the maximum incline of the railway system in question. When there are several trailer coaches per train unit, their brake solenoids can be connected with advantage, in series. When the conditions are such as described, it is possible to ensure that, during down-grade operation, each individual coach of the train unit is subjected to the same braking effect. If, however, it is a question of braking a train unit, fitted with braking appliances such as short-circuit brake on the motor coach, and solenoid brakes on the trailer coaches, and of bringing the train to a standstill, experience has shown that difficulties occur through excess braking of the trailer coaches. This is due to the fact that the brake solenoid is too highly energised by the increased braking current of the driving motors, corresponding to the retardation the train is subjected to; in other words, there is an excessive tractive effort, this being specially the case when braking is applied abruptly. Endeavours had formerly been made to remedy this trouble by giving the magnetic circuit of the solenoid a high saturation, or by providing mechanical stopping devices on the brake solenoid, which come into operation when the normal tractive effort was exceeded. Experience has, however, shown that these devices did not always have the desired effect.

The following mode of connection makes it possible to prevent, in a simple way, such excess braking. With the arrangement in question, there is, as shown in the accompanying diagram (Fig. 1), in parallel with the winding of the braking solenoid, a non-inductive resistance W_1, which causes a limited shunting of the brake solenoid winding. This shunt circuit further includes the coil of a contactor, which closes the circuit of a second shunting resistance W_2, in the event of a given current rise in the former shunt circuit.

The mode of operation is as follows: — If the normal excitation current of the brake solenoid is exceeded a little, momentarily, as may happen when regulating the braking effect with the controller of the motor coach, the additional currents do not pass through the winding of the inductive brake solenoid but through the shunt resistance W_1. In the event of a further increase of the braking current, the contactor comes into play and closes the circuit of the second shunting resistance W_2, with the result that the over-exciting of the brake solenoid and the excess braking of the wheels

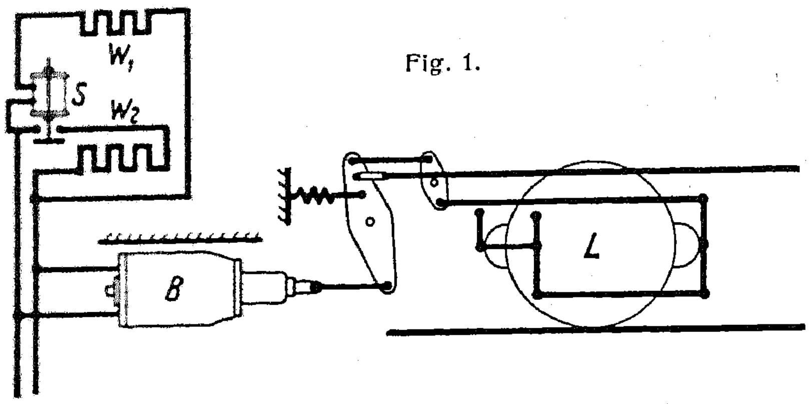


Fig. 1.

B Brake solenoid
A Set of running wheels with brake blocks and brake rigging
W_1 Shunt resistance (control circuit)
W_2 Main shunt
S Electro-mechanically controlled contactor.

is entirely prevented. Contactor and shunt resistances can be combined in various ways to suit the conditions of service. The arrangement shown in the illustration is the one the Oerlikon Co. have found most satisfactory, after testing it out on the Zurich Municipal Tramways. When this automatically controlled shunt was used, there was never any sign of locking of the wheels of the trailer coaches, even when braking abruptly.

Fig. 2a shows the current distribution in the braking circuit, for a total braking current up to 90 amps. The contactor S is not yet acting, as the current in the winding of the solenoid brake is still considerably below the danger limit where locking of the wheels would take place. Fig. 2b shows the conditions encountered during the braking of a train unit consisting of a 4-axle motor-coach of the Zurich Municipal Tramways and two trailer coaches. The total braking current reached, in this case, during the retardation period, a value of 220 amps. During that period the current distribution was as follows: —

Shunt resistance W_1	20 amps.
Shunt resistance W_2	110 amps.
Brake solenoid	90 amps.

If it had not been for this automatic shunting, these high currents would have unavoidably caused the locking of the wheels of the trailer coach; as a result, however, of the limitation of the excitation current of the brake solenoid to 90 amps, there was still a sufficient margin to prevent excess braking.

The arrangement, such as described, devised by the Oerlikon Company presents, furthermore, the great advantage over mechanical limitation of the tractive effort that the winding of the brake solenoid is protected from overload, so that excessive heating by the heavy currents encountered from time to time during braking, is not to be feared. The simple equipment required can be mounted without difficulty on any vehicle.

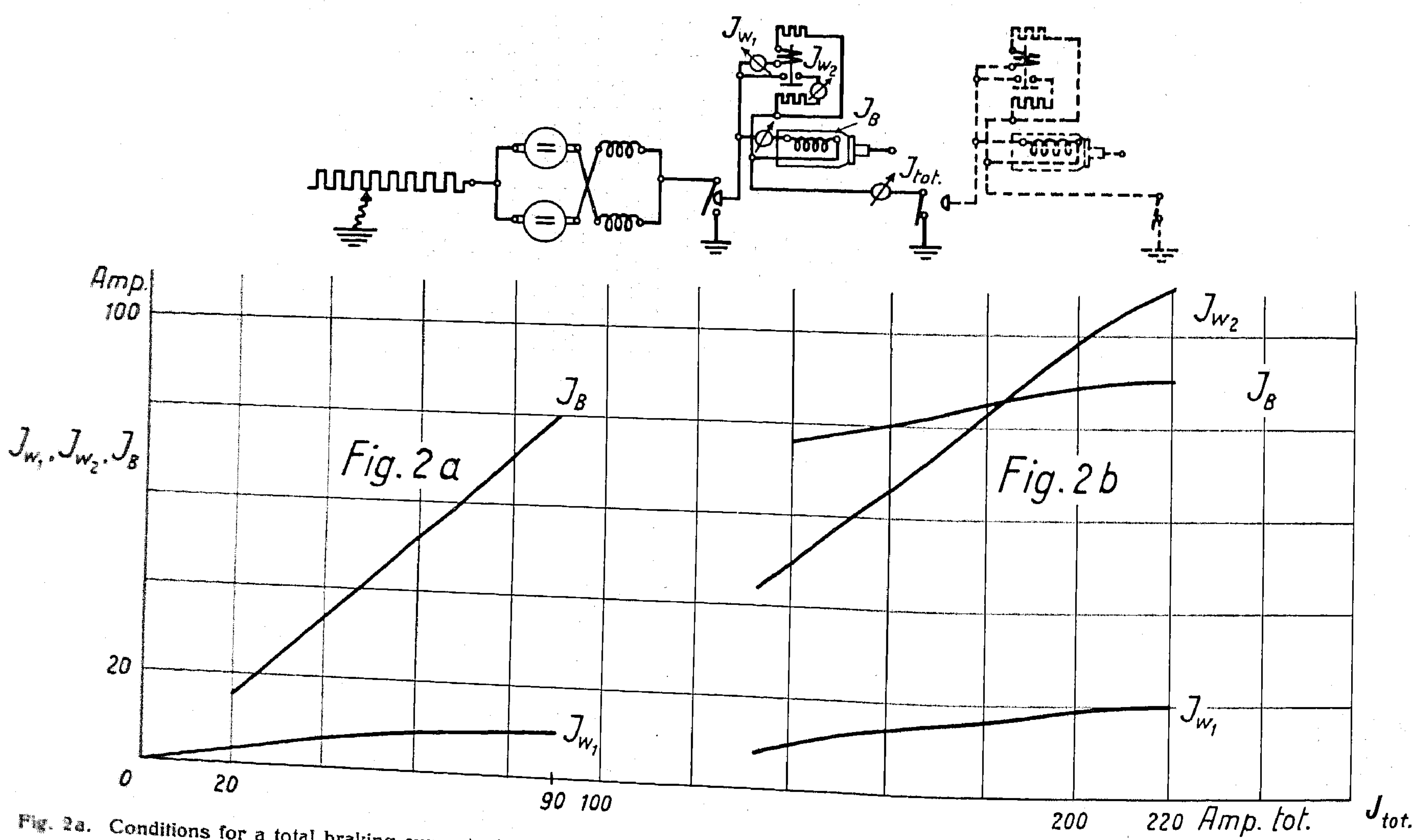


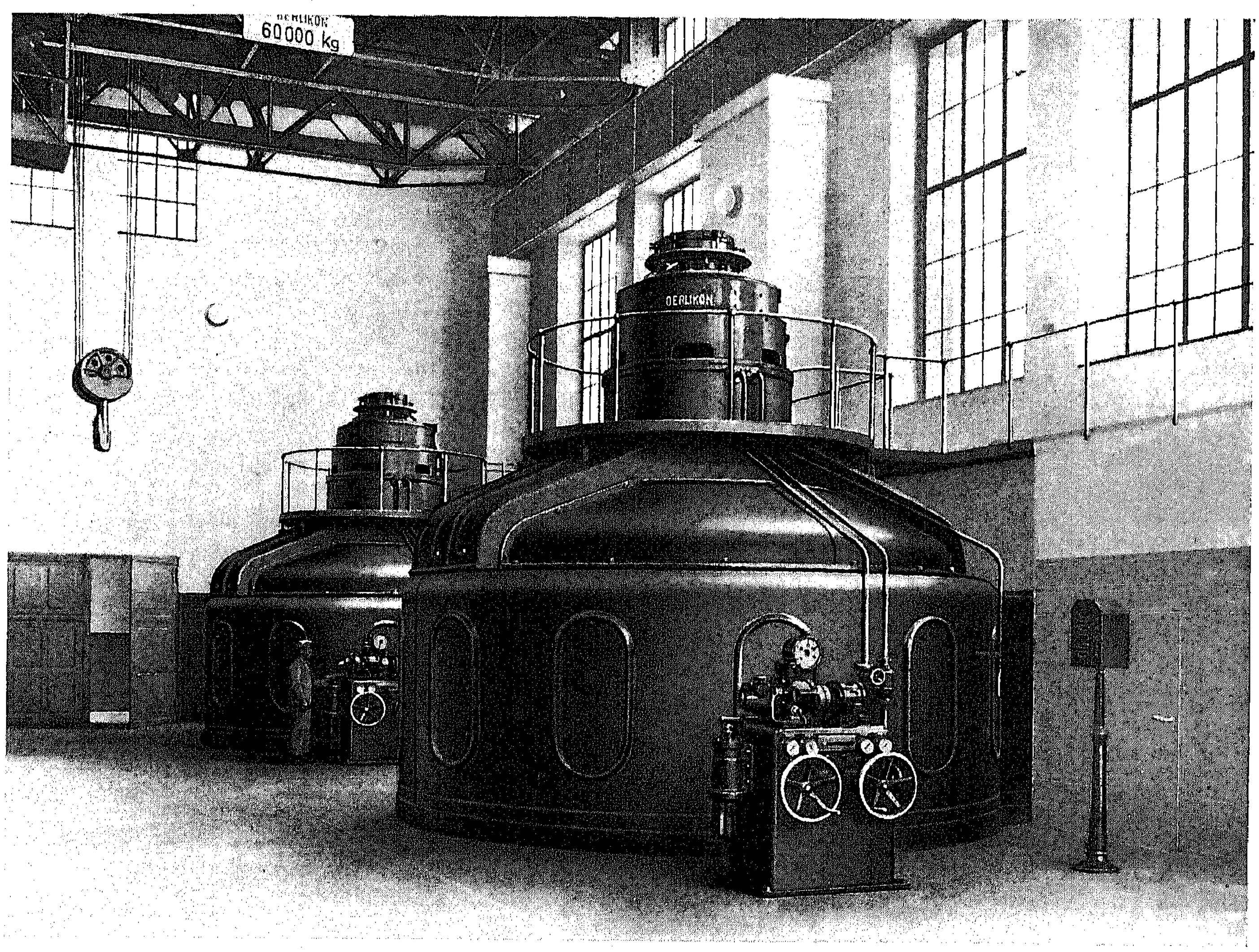
Fig. 2a. Conditions for a total braking current of 90 amps.

Fig. 2b. Conditions for a total braking current of 220 amps.

BULLETIN OERLIKON

No. 124 — October 1931

Contents:



The Burguillo Power Station of the S. A. Saltos del Alberche.

The S. A. Saltos del Alberche, Madrid, utilises the water power of the Alberche river in several steps, the first two steps being used for the Puente Nuevo and Burguillo Power Stations. The order for the complete electrical equipment of the two installations was placed with the Oerlikon Company.

In the case of the second power station, that of Burguillo, which was put into service at the end of 1930, provision has been made for three generating sets, of which two have been installed in first place. The generators are of the vertical type; they are direct coupled to turbines of the S. A. Ateliers des Charmilles, Geneva. These machines are built for a continuous rating of 18,750 KVA at 7500 volts, 375 RPM, 50 cycles. When designing the plant, it was necessary to take into account the very high runaway speed of 850 RPM. The weight of the rotating part together with the pressure exerted on the turbine by the water, amounting to 155 tons in all, is taken by a thrust bearing supported by a girder above the generator. Each generator is connected to a transformer with the same capacity and having a pressure ratio of 7500/112,500 volts. The transformers are arranged for cooling by means of built-on oil coolers with oil and water circulation. The H. T. winding has been designed very carefully, in view of the high pressure to which it is subjected. The transformers and the H. T. gear are for outdoor mounting and form an outdoor sub-station which is connected up to the machine house containing the control room with the remote control gear. The power station is provided with the most modern protective and measuring gear. The 112.5 kV oil circuit breakers are designed for a rupturing capacity of 700,000 KVA.

The first power station, that of Puento Nuevo, which was put into service in 1929, contains three sets each for 6750 KVA at 5600 volts connected to transformers with a pressure ratio of 5600/112,500 volts. It is equipped in the same way as the Burguillo Power Station.

The Parasitic Forces in Induction Machines. Part I.

By Dr. M. Krondl.

Table of contents.

I) Introduction.

The useful mechanical power in induction machines is supplied by the force applied tangentially to the rotor and stator, which, according to the Biot-Savart Law, is caused by the interaction of the first harmonic of the rotating field, and of the current distribution along the stator and rotor peripheries. There are, however, apart from this useful force, also other parasitic forces which produce no useful work and only give rise to more or less disturbing secondary phenomena. In order to obtain a better survey of the case, we propose to make a classification of the causes of parasitic forces, of the forces themselves and of their effects.

1) The causes of parasitic forces can be enumerated as follows:—
   a) The fundamental field, as it causes, apart from the torque, also radial forces.
   b) The field-harmonics due to the windings[1]) of the stator and rotor, caused by the fundamental current and by the current-harmonics.
   c) The field-harmonics due to the slots[1]) of rotor and stator.
   d) The field-harmonics of the saturation.
   e) The field-harmonics, due to the eccentricity or the lack of uniformity of the air gap.
   f) The leakage fields of the coil ends.
   g) The leakage of the main field in the axial direction on the end surfaces of the packets of laminations.
   h) The harmonics and the lack of symmetry of the voltage of the supply system.

   The causes under f), g) and h) are less important and will be neglected hereafter.
2) We shall, therefore, only deal with the forces acting in the air gap; these can be classified according to their direction in a) radial and b) tangential forces.
3) The effects of the parasitic forces are as follows:—
   a) Non oscillating deformation of the constructional parts (for instance, bending of the shaft, in the case of eccentricity of the rotor shaft in relation to the stator bore), which are produced by constant forces, stationary in relation to the stator.
   b) Parasitic torques or depressions in the torque curve (dead points); three characteristic types of such torques are encountered, which differ in respect of their shape:—
      α) asynchronous (Fig. 1a; Section IV, 2A);
      β) synchronous (Fig. 1b; Section IV, 2B);
      γ) caused by vibrations (Fig. 1c; Section IV, 1).
   c) Vibrations of the constructional parts.
   d) Noise.

[1]) For further information regarding these harmonics, see Section III.

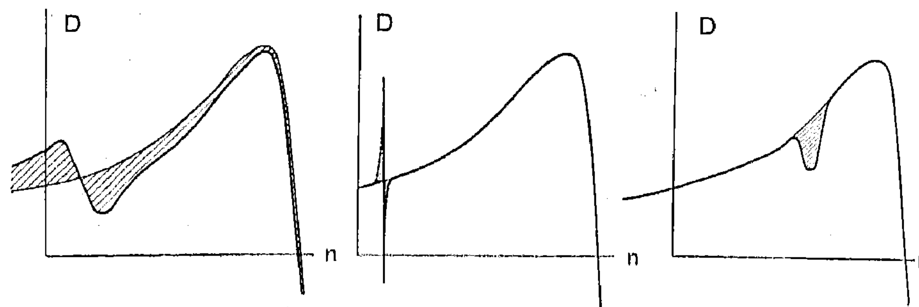


Fig. 1a–c. 1a) Asynchronous parasitic torque, 1b) Synchronous parasitic torque, 1c) Parasitic torque caused by vibrations.

The saturation of iron, the complexity of the oscillations produced, etc. render an accurate theoretical handling of the problem dealt with in this paper partly impossible. It is, therefore, hardly possible to expect everywhere thorough agreement in the matter of quantities with the measurements. The theory set out provides, however, useful guiding principles in the design of plant and fundamental data for further experimental investigations.

II) General remarks regarding mechanical oscillations and sound.

As in the following sections, we shall be dealing with mechanical oscillations and sound, as resulting phenomena of parasitic forces, we propose to explain here, without going into an exact theory, the elementary laws of oscillations and sound.

The active iron together with the constructional parts of the electric machine is a complicated mechanical oscillating system, which has a large number of natural frequencies of oscillations. Fig. 2 is an oscillogram of the free oscillations of a point of a casing of an average size motor, after another point of the casing has been hit with a

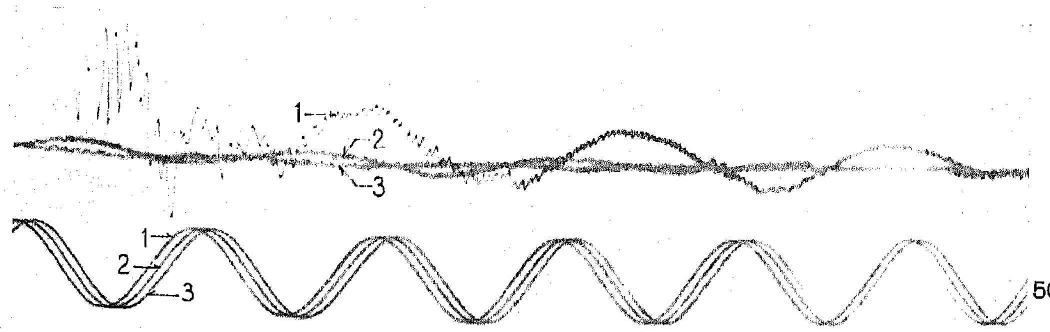


Fig. 2. Free oscillations of a point of the casing of a motor, after a blow with a hammer at another point of the casing (the oscillogram was taken during three revolutions of the oscillograph drum).

hammer. The mechanical oscillations were measured with a special microphone (see further Fig. 5). The oscillations which can be best seen on this oscillogram are those of about 33, 880 and 1400 cycles. The damping is less for the slower oscillations than for the rapid ones, so that the oscillations after a few cycles are free from higher harmonics.

As a result of the vibrating parasitic forces, the mechanical oscillating system of the machine is subjected to forced oscillations. In order to make these capable of mathematical treatment, we shall suppose, as an ideal case, that the stator and rotor together with their constructional parts form homogeneous rings. These are subjected to a series of parasitic forces. If we plot the distribution of each force at the periphery, we obtain a sine function; each force vibrates with the cyclic frequency ω_ν (see also Section IV). The following formula can be set out for the radial or tangential parasitic forces per square unit of stator surface p_ν (dyn/cm²):—

$$p_\nu = p_{\nu\,max.} \sin(\nu\xi - \omega_\nu t)\ \text{dyn/cm}^2 \qquad (1)$$

(ξ is the angular co-ordinate of the point at the periphery, ν the "number of pairs of poles" of the parasitic force. The quantity ν can also be zero; the force is then evenly distributed along the periphery). Each parasitic force imparts to the stator (and rotor) ring sine-shaped[2]) oscillations in space and time, which can be expressed by the well-known general oscillation differential equation:

$$-y_\nu k_\nu - \frac{d y_\nu}{d t} c_\nu - \frac{d^2 y_\nu}{d t^2} m_\nu = p_{\nu_{max.}} \sin(\nu\xi - \omega_\nu t) \qquad (2)$$

y_ν is the deflection of the oscillation, k_ν the coefficient of restitution, c_ν the coefficient of damping, m_ν the coefficient due to the mass.

The solution of this differential equation, expressed by means of the well-known symbolic notations used in the study of alternating current, is as follows:

$$\mathfrak{y}_\nu = -\frac{\mathfrak{p}_\nu}{k_\nu + j\,\omega_\nu c_\nu - \omega_\nu^2 m_\nu} \qquad (3)$$

[2]) The oscillations are actually not perfectly sine-shaped; as, however, the deviations are small, we shall take them as sine-shaped.

The expression in the denominator $\mathfrak{Z}_\nu = k_\nu + j\,\omega_\nu c_\nu - \omega_\nu^2 m_\nu$ (4) can be denoted as the "impedance of the mechanical oscillations". The quantities k_ν, c_ν are functions of ν, the number of "pairs of poles" of the parasitic forces (the greater the value of ν, the greater the value of the coefficient of restitution k_ν, for instance). The oscillation impedance $\mathfrak{Z}_\nu$ is, however, also a function of the cyclic frequency for a given ν and passes through a minimum, in the case of resonance when $\omega_\nu^2 m_\nu = k_\nu$. The amplitude, apart from being dependent upon the force and its distribution, is also a function of the frequency.

Fig. 3 a and b are oscillograms of the mechanical oscillations of a point of the casing of an average size induction motor at rest, with rotor open and the stator fed at 50 and 75 cycles, but with the same induction (measured with the vibrometer of Thoma[3]). It will be seen that the shape of the oscillations has altered, although the forces have remained the same. This is due to the fact that the impedances $\mathfrak{Z}_\nu$ of the individual oscillation harmonics alter in magnitude in relation to each other with the frequency.

The vibrations create sound according to the law[4]):

$$p_s = 174\, f\, y_{max}\ \text{bars}\ (= \text{dyn/cm}^2) \qquad (5)$$

p_s is the sound pressure produced in the immediate neighbourhood of the surface vibrating with the amplitude y_{max}, and gives the physical measure of the strength of sound, f is the frequency of the oscillations and 174 is a constant which applies to the air under normal conditions. The strength of sound is propagated in space according to the general laws of radiation. If, therefore, the source of sound is, for instance, a sphere, and there is no sound reflexion, the strength decreases with the square of the distance. According to equation (5), the strength of sound is not only dependent upon the amplitude of the sound propagating oscillation, but also upon its frequency.

The physiological sensitiveness of the ear to sound, is a function of the sound pressure and of the frequency. In Fig. 4, the two limit curves correspond to the

[3]) Thoma "Measuring of rapid oscillations" Z.V.D.I., Vol., 73 (1929), page 639.

[4]) K. W. Wagner. "Fundamental physic aldata of sound production", A. E. G.-Mitt., 1929, page 567.

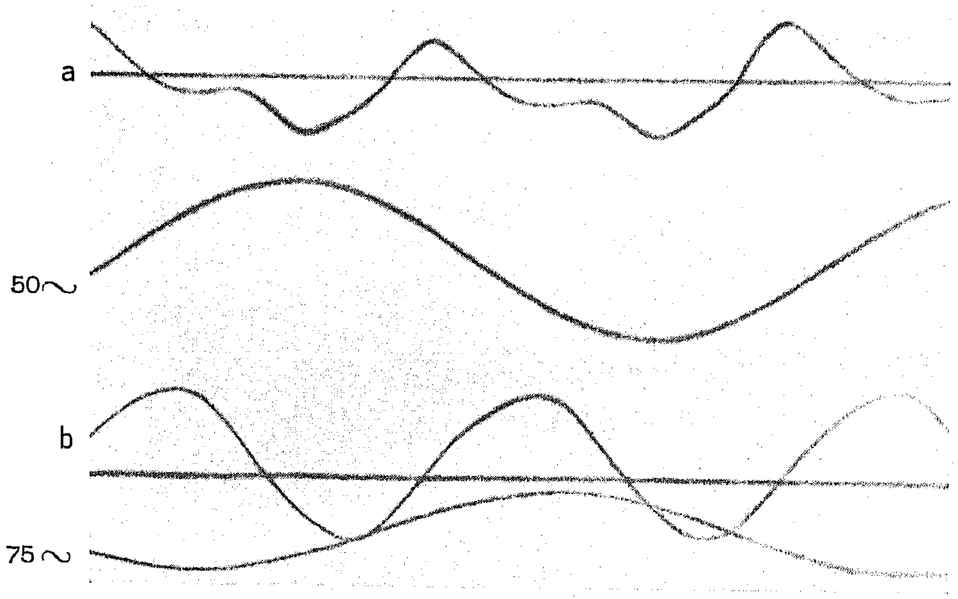


Fig. 3. Forced oscillations of a point of the casing of an induction motor at standstill, with open rotor, and stator fed a) at 50, b) at 75 cycles, with same induction in both cases.

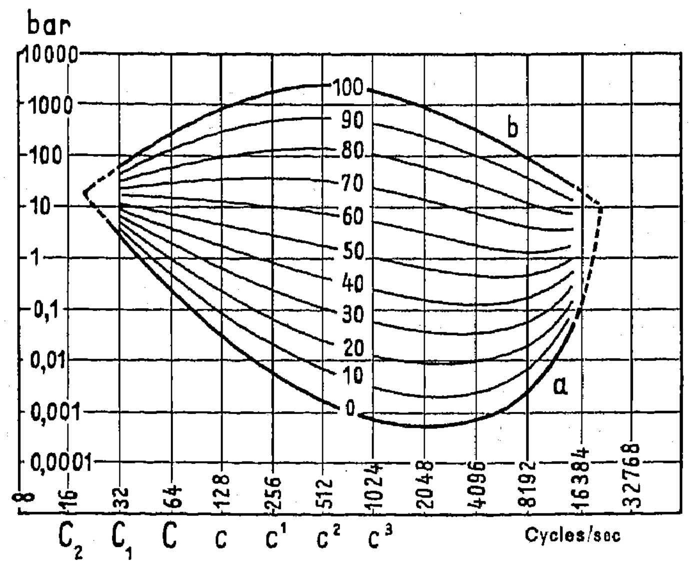


Fig. 4. Range of audibility.

a) Sound pressure curve, below which the audibility disappears.
b) Sound pressure curve, above which the painful sensations begin[4]).
0—100 are curves of same audibility.

limits of normal audibility. Below the lower curve, audibility disappears; above the upper one, painful sensations begin. If we subdivide the portion between the two curves (plotted in the logarithmic scale) into equal parts by means of a series of curves (see Fig. 4), it is possible to give in this scale the physiological audibility for each sound pressure and each frequency [5]). We are giving as example, the audibility of the following noises [6]):

Rustling of leaves in a gentle breeze		about	5
Whispering	(distance 1 metre)	„	15
Speaking	(distance 1 metre)	„	40
Noise of aeroplane	(distance 5 metres)	„	80

A large variation in the sound pressure corresponds to a relatively small alteration of audibility. If, for instance, a tone of 1000 cycles is to be reduced from the audibility of speaking (= 40, see Fig. 4) to that of whispering (= 15, see Fig. 4), the sound pressure and consequently the amplitude of the noise propagating vibration, within the meaning of equation (5), must be reduced about 40 times. It follows also that if it is desired to reduce the noise of a machine, it is necessary to weaken in a very radical way the vibrating forces, so as to ensure a marked improvement. Furthermore, it will be seen from Fig. 4 that for tones of weak and average strength, the audibility is the greatest for about 2000 cycles. A tone with the audibility of a whisper (= 15, see Fig. 4) has, for instance, at 100 cycles a 60 times greater sound pressure and, within the meaning of equation (5), a 1200 times larger amplitude of sound producing vibration than at 2000 cycles. Owing to this, in electric machines, it is mainly the field harmonics of high frequency which give rise to the unpleasant noises, although they only produce small forces.

There is no simple relation between the subjective sensitiveness to sound and the actual cause, the vibrating force, as in the process of its production, force-vibration-sound-audibility, three non-linear functions distort the simple proportionality.

Example: A machine has a bore of 20 cm, width of iron core $l = 10$ cm, height of yoke = 3 cm; the stator is subjected to a vibrating force distributed uniformly along the periphery, with an amplitude 25×10^6 dyn = 25 kgs. The elastic deformation by a stationary force of this magnitude would be: $y_0 = 1.8 \times 10^{-6}$ cm; consequently, the value of the coefficient of restitution is $k = \frac{25 \times 10^6}{1.8 \times 10^{-6}} = 1.4 \times 10^{13}$.
The mass of the stator ring together with the teeth is taken as $m = 2.5 \times 10^4$g. By referring to the oscillogram in Fig. 2, we can estimate the damping co-efficient as being $c = 5 \times 10^6$. This co-efficient varies, it is true, probably with the frequency. For the sake of simplicity, we shall make the assumption, in this informatory calculation, that it is constant. The natural cyclic frequency is $\omega_{res} = \sqrt{\frac{k}{m}} = 2.36 \times 10^4$; consequently, the natural frequency is $f_{res} = 3800$ cycles.

[5]) According to a newly published report ("Inter-society co-operation urged to expedite noise study agreement", Electrical Engineering, Vol. 50 [1931], page 443), a measuring system of audibility is in course of standardisation by the American Institute of Electrical Engineers. Most of the proposals recommend the subdivision of the range of pure tone audibility into 130 logarithmic parts (decibel).

[6]) Approximately according to Steinberg, "Noise measurements", Electrical Engineering, Vol. 50 (1931), page 42.

In Table I, we give for a few frequencies the amplitude of the vibrations, the strength of noise and the audibility (in the immediate neighbourhood of the motor).

Table 1.

Frequency f = Cycles/sec	100	1000	3800 (Resonance)	10 000
Amplitude y_{max}, cm	1.8×10^{-6}	1.9×10^{-6}	2.1×10^{-4}	2.8×10^{-7}
Strength of sound p_s, bar	0.03	0.33	140	0.49
Audibility . . . (see Fig. 4.)	0	40	90	50

Measurement of the vibrations and of the sound:

The measurements of the vibrations and of the sound which are given in this article, were made with the following devices:

1. Measurements of vibrations with the vibrometer such as devised by Thoma (for further particulars, see technical literature [3]).
2. Measurements of vibrations with the "shaker" microphone represented in Fig. 5 arranged in accordance with the ordinary telephone connection without amplifier; the current was recorded on an oscillogram. Whilst the vibrometer as devised by Thoma gives measurements of vibrations free from distortion, the shaker microphone can only be used for comparative measurements. It is, however, in most cases, not so much a question of determining exactly the amplitude, but rather of arriving at the frequency. The shaker microphone is very easy to handle. It is glued with paraffin to the point to be measured; it is only influenced by vibrations and not by noise, so that the measurements can be carried out in a noisy workshop or test room.
3. Measurements of noise with a sensitive carbon microphone arranged in accordance with the ordinary telephone connection, without amplifier valves, the current being recorded on oscillograms. In the case of the carbon microphone too, it is not possible to expect a recording of noise without distortion; there is between the sound pressure p_s and the microphone current a complicated relation, see Fig. 6[7]).

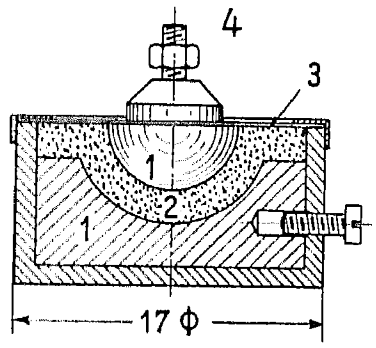


Fig. 5. Shaker microphone
Trade mark: Skinderviken.
English patent No. 120734 (1917).
1 Carbon electrodes
2 Granulated carbon
3 Mica diaphragm
4 and 5 Terminals

[7]) Trendelenburg, Zeitschrift für Hochfrequenztechnik, Vol. 37 (1931), page 105.

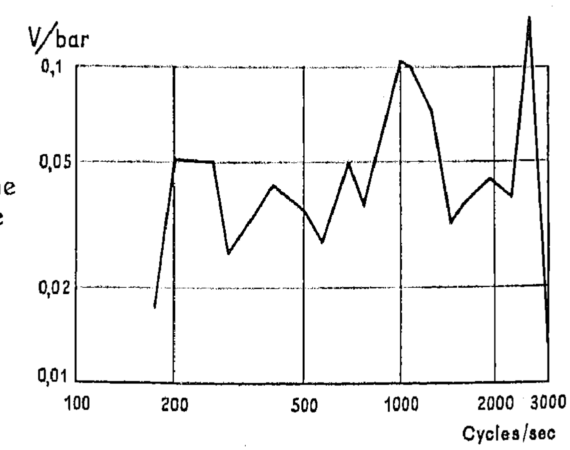


Fig. 6. Relation between the carbon microphone voltage and the frequency [7]).

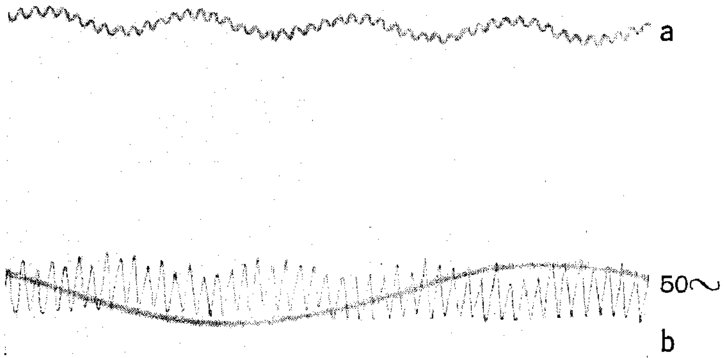


Fig. 7. Oscillogram of a compound tone,
a) with a condenser microphone,
b) with a carbon microphone.

In Fig. 7, we have reproduced an oscillogram of a compound tone with a condenser microphone and a carbon microphone. The carbon microphone gives in a more pronounced way the higher frequency, which in fact approaches more the subjective sensitiveness and is thus not undesirable.

4. The simplest method for the approximate determination of the subjectively felt strength of noise of electric machines is the comparison of the noise to be measured with a source of noise calibrated according to an arbitrary scale. For this purpose, use can be made, for instance, of an induction motor, of which the noise is altered when the pressure is varied[8]).

III) Harmonics due to the windings and slots.

The current distribution (expressed in ampere-conductors per cm of stator or rotor periphery) and the magnetic field, which occur in induction machines are harmonic functions of the time and place, and can be resolved into a Fourier series.

In the following sections, it will be shown that the occurrence of parasitic forces is the outcome of these harmonics. The essential points relating to the most important harmonics, namely the field harmonics due to the windings and slots are recapitulated below.

1. Harmonics due to the windings.

a) In the case of symmetrical poly-phase windings, the νth harmonic of the current distribution is

$$a_\nu = A_1 \frac{k_\nu}{k_1} \sin (\nu p \xi \mp \omega t) \qquad (6)$$

A_1 is the amplitude of the first harmonic of the current distribution

$$A_1 = \frac{N_1 I_{max}}{\pi D} k_1 \qquad (7)$$

where k_1, k_ν are the winding factors of the first and νth harmonic (for the value of $\frac{k_\nu}{k_1}$ for three-phase windings see Table 2), p is the number of pairs of poles of the fundamental field, ξ the angular co-ordinate of the point at the periphery of the stator bore, $\omega = 2\pi f$ the cyclic frequency of the current, N_1 the number of conductors through which the current I flows, $I_{max} = \sqrt{2}\, I_{eff}$, the maximum value of the current, D the diameter of bore.

The νth field harmonic due to the νth harmonic of the current distribution (assuming an even air gap and an infinite permeability of the iron) is:

$$b_\nu = B_1 \frac{I}{I_0} \frac{k_\nu}{k_1 \nu} \sin (\nu p \xi \mp \omega t) \qquad (8)$$

where I_0 is the magnetising current, I the current flowing through the winding and inducing the field harmonic, B_1, the amplitude of the fundamental field corresponding to the magnetising current I_0.

The order of the harmonic is:

$$\nu = 2cm \pm 1 \qquad (9)$$

where c is a whole number. The + sign in equation (9) corresponds to $-\omega t$ in equation (6) and vice-versa; the field harmonic with $-\omega t$ revolves in the synchronous direction.

Of the endless series of harmonics the following harmonics reach large amplitudes: the lowest $\nu = 2m \pm 1$ (in the case of three-phase current, the fifth and seventh), and furthermore the $\left(\frac{N}{p} \pm 1\right)^{th}$, as for the latter $\frac{k_\nu}{k_1} = 1$ (N is the number of slots).

b) In the case of assymetrical multi-phase windings and windings with a fractional number of slots per pole and phase, the harmonics can be determined by means of the graphical method of Brüderlin[9]). The quantities ν may assume a fractional value and even be smaller than 1.

[8]) This method has been used for years by the Oerlikon Company. See also, for instance: Hildebrand, "Quiet induction motors", I.A.I.E.E., Vol. 49 (1930), page 6.

[9]) Brüderlin: On the graphical resolution of the current distribution of an irregular multi-phase winding into its harmonics. E.T.Z., Vol. 42 (1921), page 1093.

Table 2. $\frac{k_\nu}{k_1}$ for three-phase windings (pitch of winding y = 1 and alternatively y = abt. 5/6).

q	y	k_1	$\nu =$ (−) 5	(+) 7	(−) 11	(+) 13	(−) 17	(+) 19	(−) 23	(+) 25	(−) 29	(+) 31	(−) 35	(+) 37
1	3/3	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1
2	6/6	+0.966	+0.268	−0.268	−1	−1	−0.268	+0.268	+1	+1	+0.268	−0.268	−1	−1
	5/6	+0.933	+0.072	−0.072	−1	−1	−0.072	+0.072	+1	+1	+0.072	−0.072	−1	−1
3	9/9	+0.96	+0.226	−0.185	−0.185	+0.226	+1	+1	+0.226	−0.185	−0.185	+0.226	+1	+1
	8/9	+0.945	+0.150	−0.065	−0.065	+0.150	+1	+1	+0.150	−0.065	−0.065	+0.15	+1	+1
4	12/12	+0.957	+0.214	−0.165	−0.132	+0.132	+0.165	−0.214	−1	−1	−0.214	+0.165	+0.132	−0.132
	10/12	+0.925	+0.057	−0.044	−0.132	+0.132	+0.044	−0.057	−1	−1	−0.057	+0.044	+0.132	−0.132

The signs in front of the order ν of the field harmonic denote the direction of rotation: (+) the synchronous, (−) the anti-synchronous direction.

c) In the case of squirrel cage windings, the value $k_1 = k_\nu$ 1 is to be introduced in the formulae 8 and 6. We have furthermore:

$$\nu = c\,m \pm 1 \tag{10}$$

where $m = \frac{N}{p}$ (N is the number of bars).

The νth field harmonic of stator induces in the squirrel cage a current harmonic which has ν_1 waves per double pole pitch. The squirrel cage is for this current a $\frac{m}{\nu_1}$-phase cage and there are within the meaning of formula (10), the following harmonics

$$\nu_2 = c\,m \pm \nu_1 \tag{11}$$

2. Field harmonics due to the slots.

Owing to the slots, the following harmonics are produced:

$$\nu = c\frac{N}{p} \pm 1 \tag{12}$$

In the case of the strongest, i. e. for $c = 1$, we have approximately the expression

$$b_\nu = B_1 (k_c - 1) \sin(\nu p \xi \mp \omega t) \tag{13}$$

k_c is the Carter coefficient of the corresponding lamination surface. The sign + in equation (12) corresponds to $(-\omega t)$ in equation (13). The $\left(\frac{N}{p}-1\right)^{th}$, $\left[\left(\frac{N}{p}+1\right)^{th}\right]$ harmonic adds itself vectorially to [subtracts itself from] the field harmonic of same order due to the winding, so that the resulting amplitude of the $\left(\frac{N}{p} \mp 1\right)^{th}$ harmonic is given by the following equation:

$$B_{\frac{N}{p} \mp 1} = B_1 \left| \frac{\mathfrak{F}}{\mathfrak{F}_0} \frac{1}{\nu} \pm (k_c - 1) \right| \tag{14}$$

Meaning of letters as above, see also equation (8).

Rotating angular velocities and frequencies. The rotating angular velocity of a harmonic expressed by one of the equations 6, 8, 13 is:

$$\omega_{uml} = \pm \frac{\omega}{p\,\nu} \tag{15}$$

The field harmonics due to the winding and slots of the stator (rotor) induce in the stator (rotor) winding the same cyclic frequency as the fundamental field i. e. $\pm\omega$, $(\pm s\omega)$ (s is the slip of the rotor relative to the fundamental field).

If ω_i is the cyclic frequency of a νth harmonic in relation to the stator (rotor) and ω_{mech} the relative angular velocity of the rotor (stator), we have in the rotor (stator) the cyclic frequency:

$$\omega_2 = \omega_1 - \omega_{mech}\, p\,\nu \tag{16}$$

If the rotor has a slip s, the ν_1th field harmonic of the stator produces in the rotor the cyclic frequency

$$\omega_2 = \omega\,[\pm 1 - (1-s)\,\nu_1] \tag{17}$$

and the ν_2th field harmonic of the rotor causes in the stator the cyclic frequency

$$\omega_1 = \omega\,[\pm s + (1-s)\,\nu_2] \tag{18}$$

The + (—) sign is to be used in the case of a harmonic rotating synchronously (anti-synchronously).

Example: see below.

IV) The production of parasitic forces.

The current distribution of the stator (and of the rotor) can be expressed in a Fourier series (see also Section III):

$$a = \Sigma A_\nu \sin(p\nu\xi - \omega_\nu t + \varphi_\nu) \tag{19}$$

We assume, in the most general case, that the individual harmonics have not only a different number of pairs of poles νp, but that they may also have different cyclic frequencies ω_ν and phase displacements φ_ν.

The current distribution of the stator and of the rotor produce together a resultant magnetic field which is affected by the size and eccentricity of the air gap, by the saturation of the iron path and by the slots. It can be expressed as a Fourier series too:

$$b = \Sigma B_\mu \sin(p\mu\xi - \omega_\mu t + \varphi_\mu) \tag{20}$$

According to the well-known law (Maxwell), this magnetic field gives rise to radial tractive efforts in the air gap:

$$p_r = \frac{b^2}{8\pi} \text{ dyn/cm}^2 \tag{21}$$

or, if we introduce the equation (20):

$$p_r = \frac{1}{8\pi}\left[\Sigma B_\mu \sin(p\mu\xi - \omega_\mu t + \varphi_\mu)\right]^2 \text{dyn/cm}^2 \tag{22}$$

Furthermore, as a result of the interaction of the magnetic field and of the current distribution, we have, according to the Biot-Savart Law, tangential tractive efforts

$$p_t = b\frac{a}{10} \text{ dyn/cm}^2 \tag{23}$$

If we introduce the equations (19) and (20) in equation (23), we have:

$$pt = \frac{1}{10}\left[\Sigma\Sigma A_\nu B_\mu \sin(p\nu\xi - \omega_\nu t + \varphi_\nu)\sin(p\mu\xi - \omega_\mu t + \varphi_\mu)\right]\text{dyn/cm}^2 \tag{24}$$

(To follow).

Example: Stator: $m_1 = 3$, $2p = 4$, $N_1 = 24$, $k_{c1} = 1.2$;

Squirrel cage: $N_2 = 27$, $m_2 = 13.5$, $k_{c2} = 1.1$, $B_1 = 7000$, $I_k = 20\,I_o$.

Under short-circuit conditions, we have, if we neglect saturation, the field harmonics according to Table 3.

Table 3.	Stator						Rotor			
	(—) 5	(+) 7	(—) 11	(+) 13	(—) 17	(+) 19	(—) 12.5	(+) 14.5	(—) 26	(+) 28
Field harmonics due to the winding: B_ν, approx.	7500	5300	12700	10800	2200	2000	11200	9600	5400	5000
„ „ „ „ „ slots: B_ν, approx.			1400	1400			700	700		
Field harmonic due to the winding + field harmonic due to the slots: approx.	7500	5300	14100	9400	2200	2000	11900	8900	5400	5000

As example of an application of equation (11), we shall set down the following: The 13th field harmonic induces in the squirrel cage a 13th current harmonic; the latter creates the following field harmonic: $\nu_2 = 0.5 \quad 26.5 \quad 14 \quad 40$

$p\nu_2 = 1 \quad 53 \quad 28 \quad 80$

Developments in OERLIKON Motor Oil Pump Design.

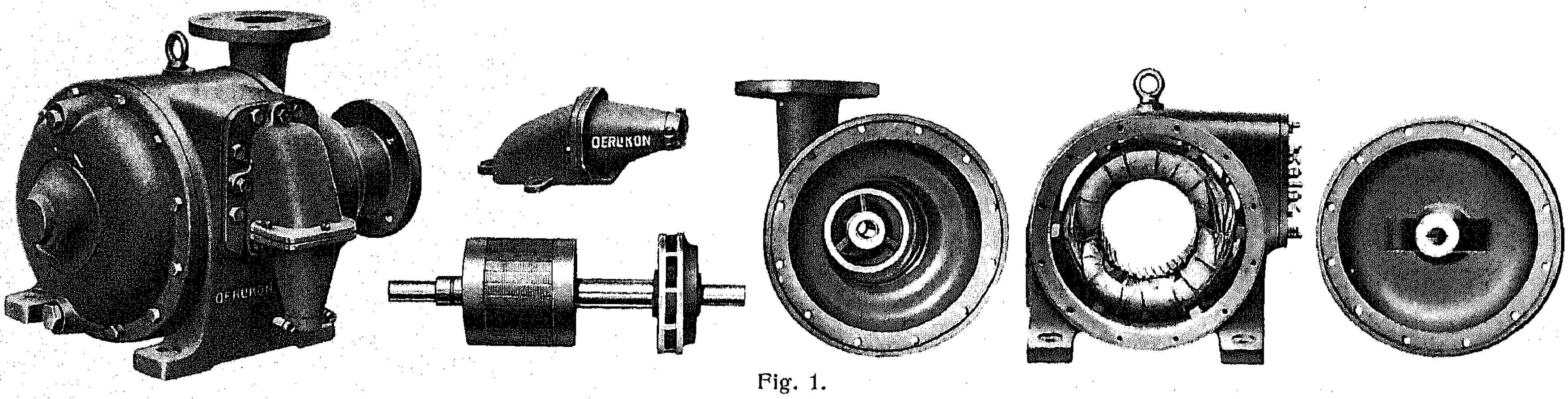


Fig. 1.

The Oerlikon Co. have been building for some years an oil pump, which is designed as an integral part of the electric motor, so that the electric winding and the rotor itself are entirely immersed in oil. It is thus possible to dispense with a stuffing box between motor and pump. Fig. 1 represents a motor oil pump of this description completely erected and also shows its component parts. The rotating part consists of the impeller of the centrifugal pump and of the squirrel cage armature of the motor, which is often built in the form of a double cage armature, in order to reduce the starting current when switching on the motor, the two being mounted on a hollow shaft. The stator winding is designed and impregnated as in the case of a standard motor. The outer bearing shield and the pump casing are each fitted with a bearing bush. The impeller is arranged in the pump casing with a small radial clearance, as can be seen from Fig. 2. A small part of the circulating oil can pass into the motor casing through this gap; it is, however, led back through the hollow shaft to the suction branch of the pump. This small quantity of circulating oil is entirely sufficient for cooling the stator winding and the rotor, and for the lubrication of the bearings. As the bore of the hollow shaft is large as compared with the gap at the periphery of the impeller, the oil pressure in the motor casing is nearly the same as in the suction branch of the pump.

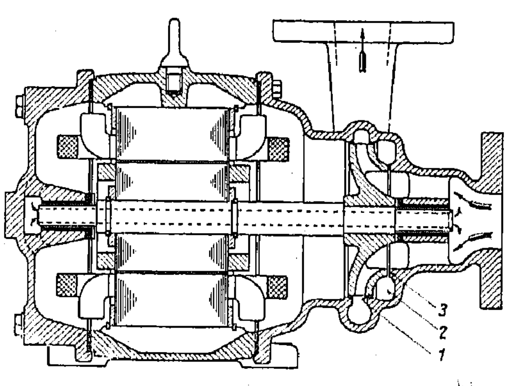


Fig. 2.

Special attention has been paid to the balancing of the axial thrust acting on the impeller. The impeller is subjected, on the one hand, to the oil pressure in the motor casing and, on the other hand, to the oil pressure in the suction branch of the pump. The oil pressure in the motor casing is, of course, always somewhat greater than in the suction branch; consequently, the impeller is pressed towards the suction branch. This axial pressure could be taken by the end surfaces of the bearing bush.

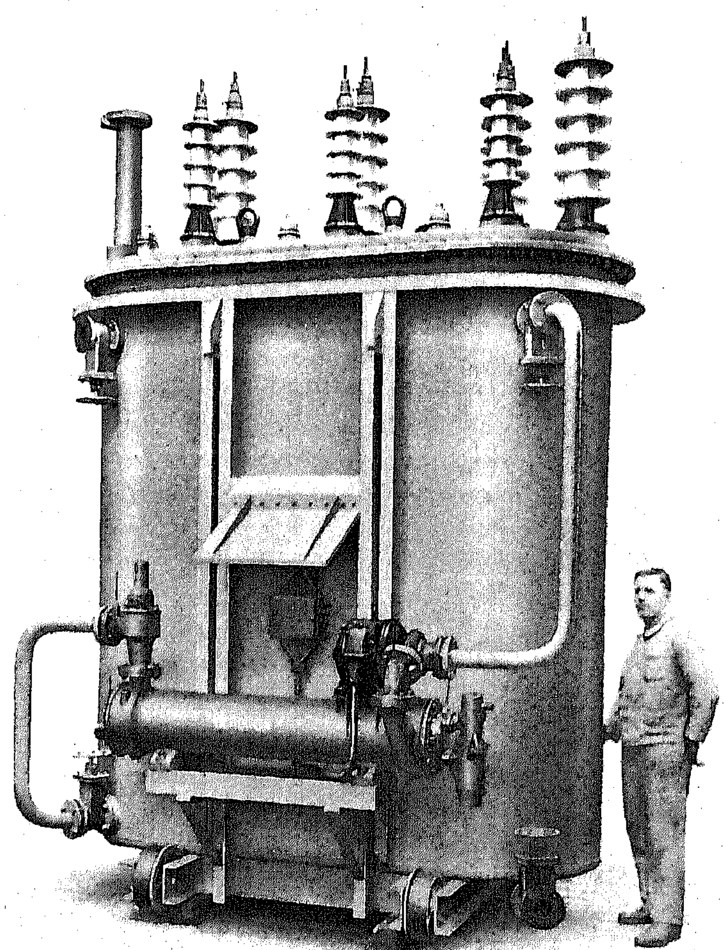


Fig. 3.

This entails, however, a certain wear of the bearing bush, which is obviated by adopting the following arrangement:— A further narrow gap 3 is provided on the side of the impeller. As soon as the impeller is pressed towards the suction branch, the gap 3 closes and the oil in the chamber 2

can no longer flow into the suction branch. This causes a higher oil pressure, dependent upon the manometric head of the pump. The impeller is pushed away from the suction branch and the gap 3 opens, so that the excess pressure of oil in the chamber 2 disappears again, while only a small quantity of oil can flow through the gap 1. It can now easily be seen that the gap 3 adjusts itself in such a way that the axial thrust exerted on the impeller is the same on both sides, and the bearing bush is thus relieved of axial pressure. This arrangement is protected by patents.

The efficiency of such motor oil pumps is as high as that of an ordinary centrifugal pump provided with stuffing box and driven by an air cooled motor. The friction losses of the armature revolving in oil are therefore no larger than those due to the friction of the stuffing box, including the windage losses of the motor and coupling.

The motor oil pumps are manufactured in series; they can be used whenever it is a case of handling oil which is practically free from water and acid. This condition is satisfied, in the first place, in the case of transformer oil. As transformers are, in most cases, mounted in the open, the motor oil pump has also to be made weather-proof; the motor is therefore provided with a water-tight cable box. The plant requires no attention, as the two bearings are immersed in oil.

There are, at present, in use more than 100 Oerlikon motor oil pumps serving as circulating pumps for the cooling of transformers. Fig. 3 shows a cooling equipment where the motor oil pump is mounted directly on the cooler. In Fig. 4, the motor oil pump is arranged separately. In the latter case, the motor oil pump is driven off a 16-2/3 cycle single-phase supply; this plant has been running for several years with the best results. Although, with 16-2/3 cycles, the speed of the motor cannot exceed 970 RPM, it is possible to obtain, with a single impeller having not too large dimensions, a moderate manometric delivery head such as is sufficient in most cases.

When higher pressures are required, the Oerlikon Co. build multi-stage pumps on the same principle. Another course, which has been resorted to with the best results, is to insert reduction gears between motor and pump. The gears themselves are then also immersed in oil. With this type of pump, any desired heads can be obtained with a single impeller.

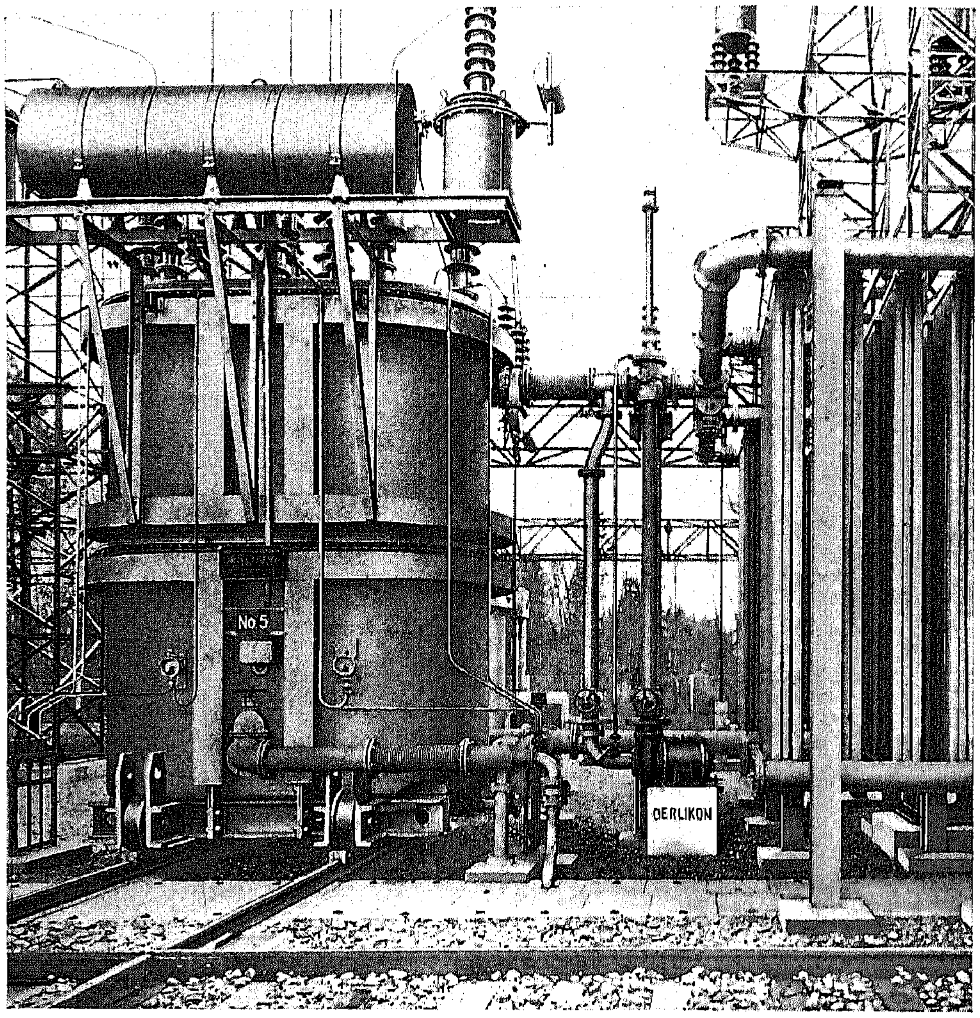


Fig. 4.

Another field of application for motor oil pumps is in connection with electric oil drying out plant, such as shown in Figs. 5 and 6. The motor oil pumps have to deal with oil at 220—255 ° F, and work without any trouble.

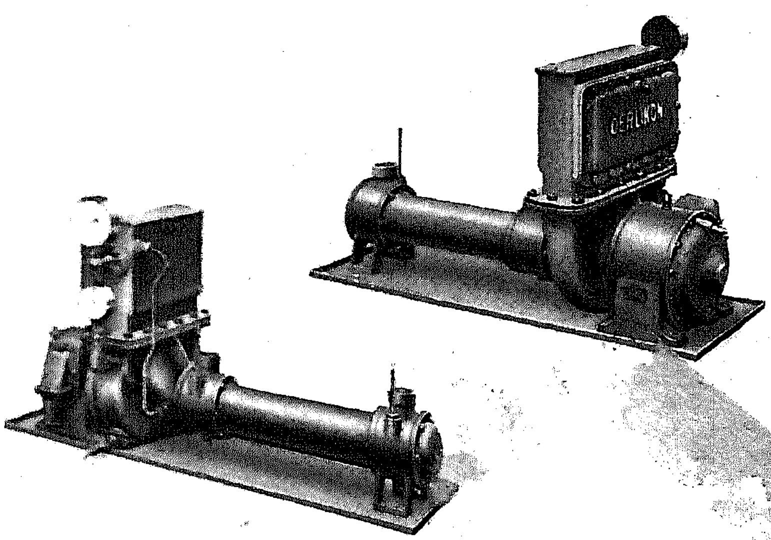
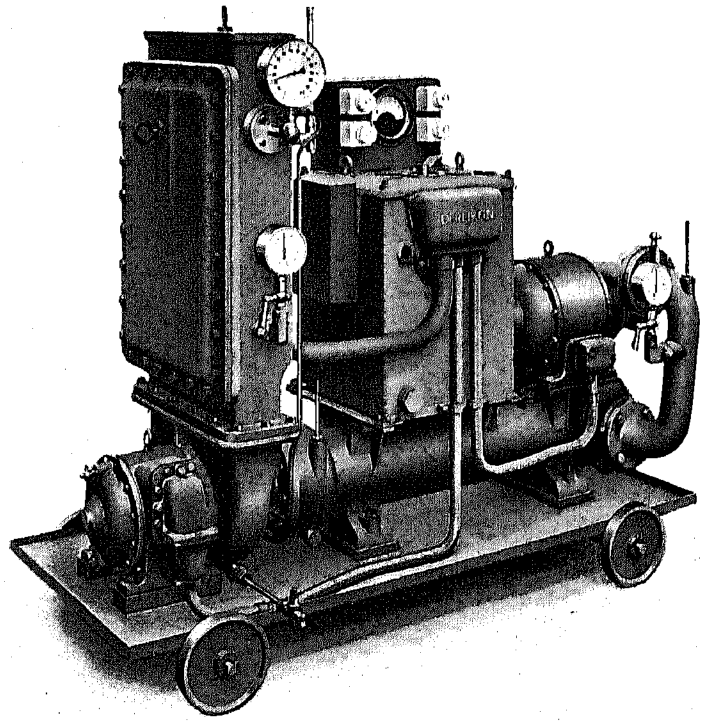


Fig. 5.


Fig. 6.

ATELIERS DE CONSTRUCTION OERLIKON, OERLIKON

BULLETIN OERLIKON

No. 125 — November 1931

Contents:

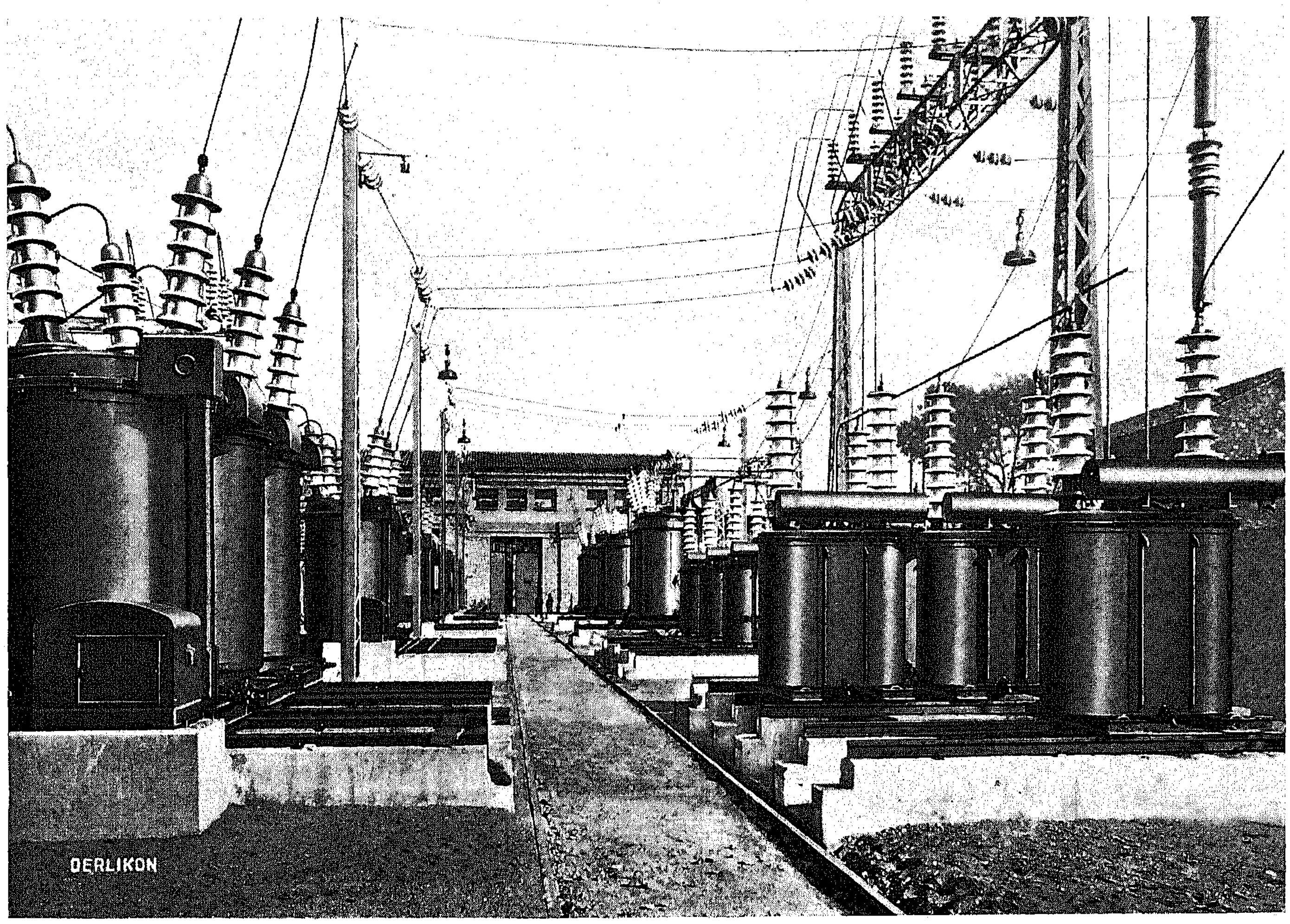


Fig. 1. Partial view of the Puente Nuevo outdoor installation (on the left, set of oil circuit breakers; on the right, main transformers and potential transformers).

OERLIKON Plant Supplied to Spain.

During the last years of the Dictatorship there prevailed in Spain great building activity. This must be ascribed in a large measure, to the very considerable financial support given by the State to new concerns, or under consideration at the time. The building activity came, however, to an end with the fall of Primo de Rivera, as the subsequent governments had in the very first place to aim at balancing the budget of the country. This difficult task, which is not yet completed, has been passed on to the young republic, so that, for the time being, further developments must rest entirely with private enterprise. This has, however, given the opportunity of making a more thorough study of the projects at present under consideration and of gauging more accurately the prospects of developments, more especially with regard to railway electrification. It may therefore be expected that, within the next few years, there will be once more a resumption of building activity.

We propose to describe below a few hydro-electric installations for which the Oerlikon Company have supplied the whole electrical equipment.

Saltos del Alberche.

The river Alberche has its source about 150 km (93 miles) west of Madrid, in the Sierra de Gredos, and is a tributary of the river Tajo. As in the case of all rivers in Spain, the Alberche has a water level fluctuating very considerably according to the time of the year. While in winter a flow of 600 to 800 m^3/sec (21200 to 28200 cu. ft/sec) is not exceptional, in summer the figure amounts hardly to 5 m^3/sec (176 cu. ft/sec).

The Saltos del Alberche Company proposes to utilise the water power of the river Alberche by erecting low head and high head power stations with or without storage reservoirs.

Fig. 2 shows the general scheme. The Puente Nuevo and Burguillo power stations indicated there, as well as the Madrid substation, are already in operation. The main distribution area for the energy produced by the power stations is the Madrid district. Provision is also being made for the supply of the Northern Railway between Madrid and Avila. Furthermore, a line is to be run in a northward direction as far as Avila and Segovia, while distribution in a southern direction is also planned for the near future.

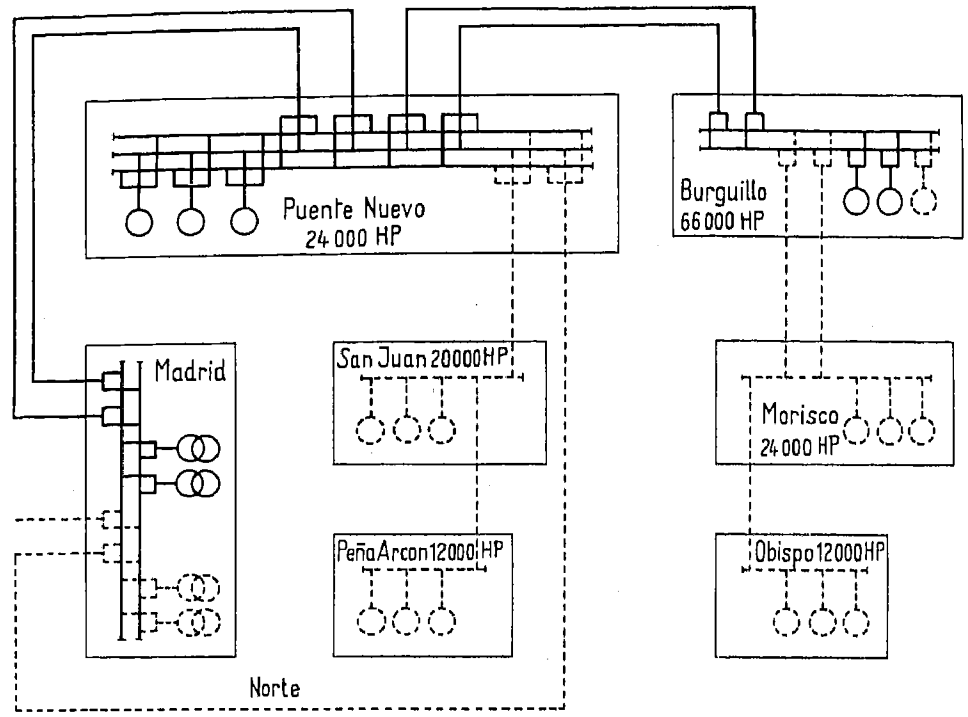


Fig. 2. Single-pole diagram of connections of the power stations on the river Alberche and of the 110 KV lines.

Puente Nuevo.

The first of the power stations on the river Alberche to be put into service was the Puente Nuevo generating station. This installation was started up in the summer of 1929. Last spring this power station was further extended, owing to provision being made for distribution at a medium pressure of 35,000 volts. Puente Nuevo, as can be seen from the general diagram in Fig. 2, can be regarded as the main distribution station. The water for driving the turbines is derived from the Charco del Cura, a storage reservoir with a capacity of about 3,000,000 m³ (106,000,000 cu. ft), with which it is linked up by means of a pressure pipe line 6 km (3.7 miles) long. The 3 turbines work under a head of 63 m (208 ft); they were supplied by the Ateliers des Charmilles, Geneva, and each develop 8150 HP. The order for the whole electrical equipment was placed with the Oerlikon Company.

The generators (see Fig. 4) are direct coupled to the turbines which are of the vertical type; they develop 6750 KVA at 500 RPM, 5600 volts, 50 cycles and power factor .8. The machines are of the totally enclosed type, the cooling air being drawn in from the machine room and led away through special ducts communicating directly with the outside. The cooling air penetrates also into the upper part of the rotor through ducts in the stator and in the supporting girder. The supporting girder carries the thrust bearing which is designed for a load of 46 tons, and the direct coupled exciter; the latter can give 570 amps. at 117 volts. Guide bearings are provided in the supporting girder and in the so-called guide frame, which hold the shaft on both sides of the rotor. A third guide bearing is fitted in the casing of the turbine. The stator is in two parts and is provided with a coil winding; the latter was tested with a pressure of 17,000 volts to earth and between phases. The test pressure applied to the individual coils was 25000 volts to earth for 1 minute. An efficiency of 96.8 % was obtained for the generator.

There is a transformer for each generator; these transformers have a capacity of 6750 KVA and a pressure ratio of 5.6/112.5 KV at full load, the mode of connection being delta-star, with neutral point brought out. These transformers are mounted in the open (see Fig. 6) and are cooled by the Oerlikon method of oil circulation. The initial turns (5%) and those next to the neutral point (2%) are provided with reinforced insulation and tested between turns with the full phase pressure. The test pressure applied between H. T. winding and

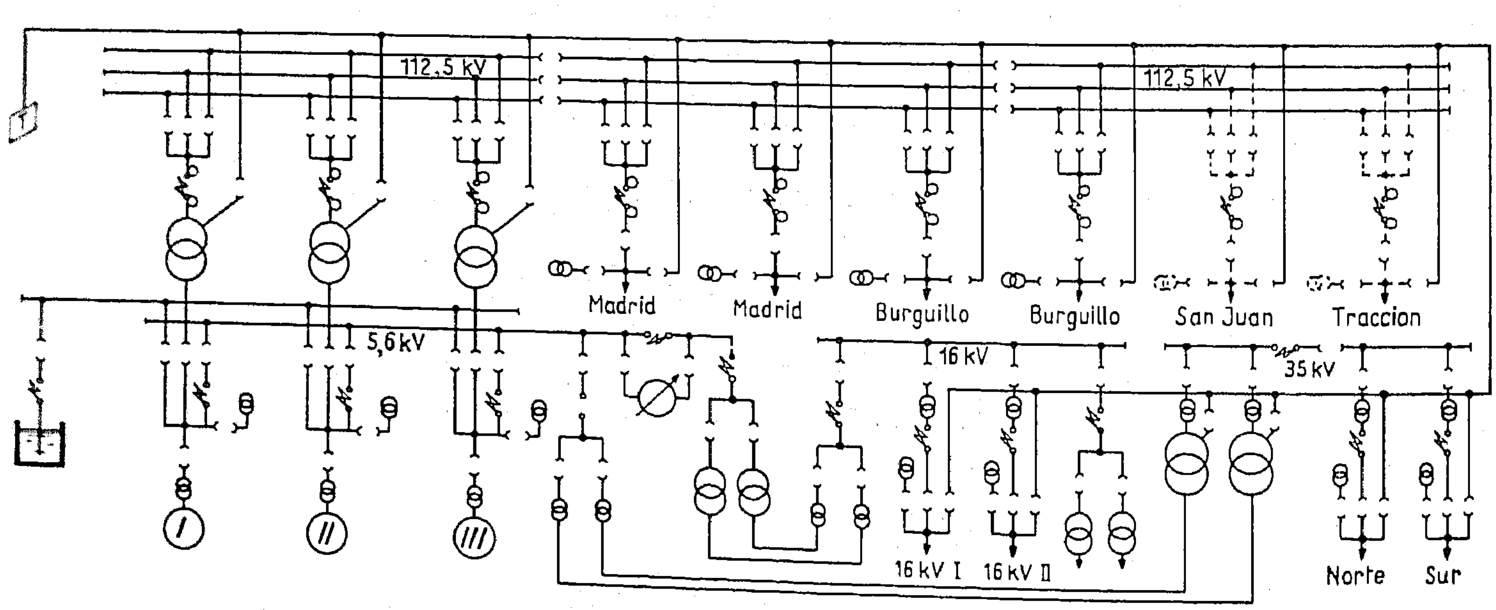


Fig. 3. General diagram of connections of the Puente Nuevo installation.

L. T. winding and earth was 225 KV. The figure of 98.5 % guaranteed for the efficiency was duly obtained by measurements. The bushings used both for the main transformers and for the potential transformers and for the 112.5 KV oil circuit breakers are bushings of the condenser type. The star point of the transformers is connected directly to earth.

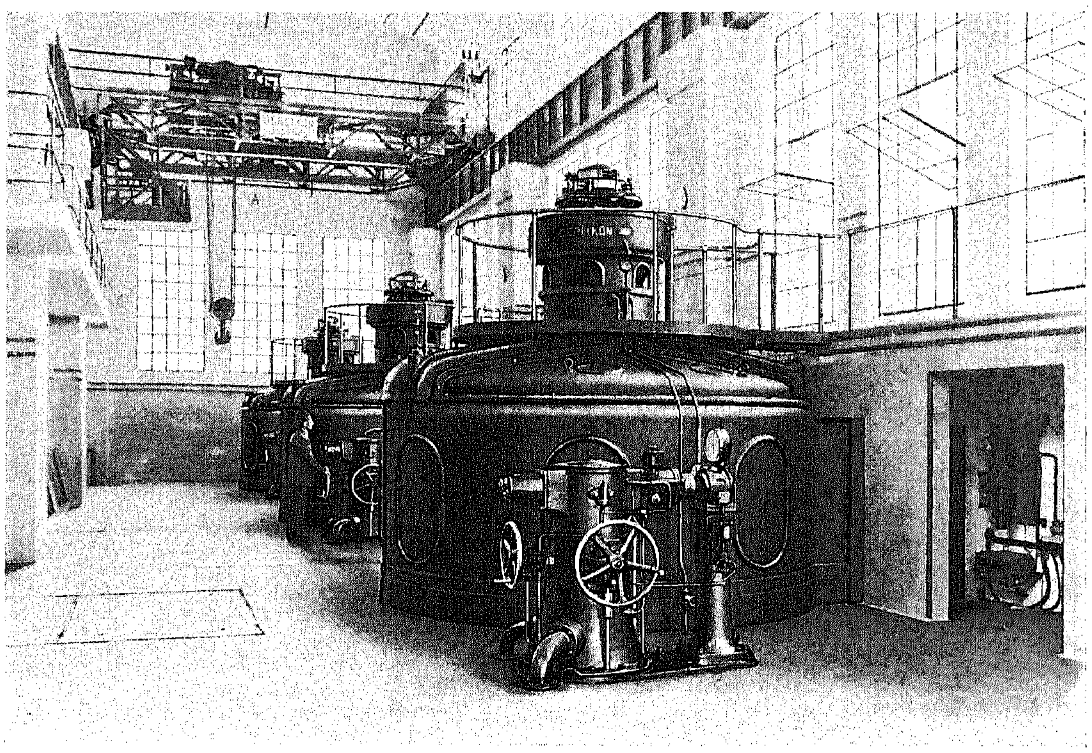


Fig. 4. Machine room of the Puente Nuevo power station.

The diagrammatical arrangement of the switchgear can be seen from Fig. 3. Each generator works directly on to its own transformer. Provision is, however, made for auxiliary busbars for feeding any other of the transformers in the case of emergency. The 112.5 KV distribution installation which is built as an outdoor station, reproduces exactly the diagram of connections in its simple lay-out permitting of the easy survey of plant (see Fig. 5). Copper cable with a section of 185 mm² (.287 sq. in.) has been used nearly throughout the installation for the conductors. Endeavours have been made to prevent as far as possible corona effect by fitting protective sleeves over the terminals for the various connections and branching off circuits. The installation comprises three systems of busbars extending throughout its length, which permit of simultaneous working on several independent distribution systems; these busbars are subdivided by means of isolating switches. Provision is made in the case of each incoming or outgoing line for a set of three single-phase potential transformers, the second terminal of these potential transformers being linked up so as to form a star point, and connected directly to earth. The current transformers are fitted on the bushings of the oil circuit breakers.

Special mention can be made of the 8 oil circuit breaker equipments, including the standby set (see illustration on front page), consisting each of single-pole circuit breakers coupled together. These high capacity oil circuit breakers are capable of interrupting a short circuit output of 700,000 KVA

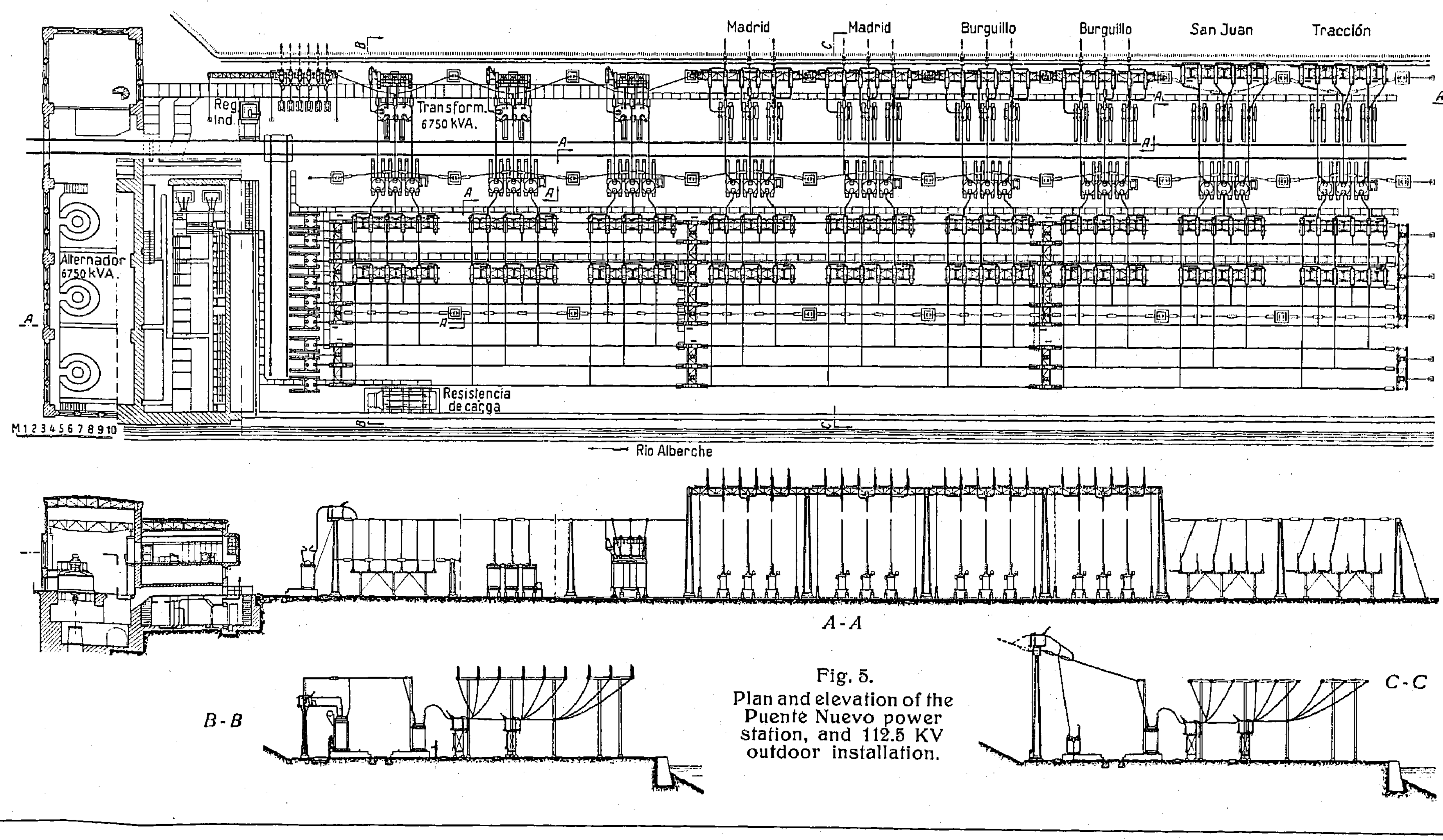


Fig. 5.
Plan and elevation of the Puente Nuevo power station, and 112.5 KV outdoor installation.

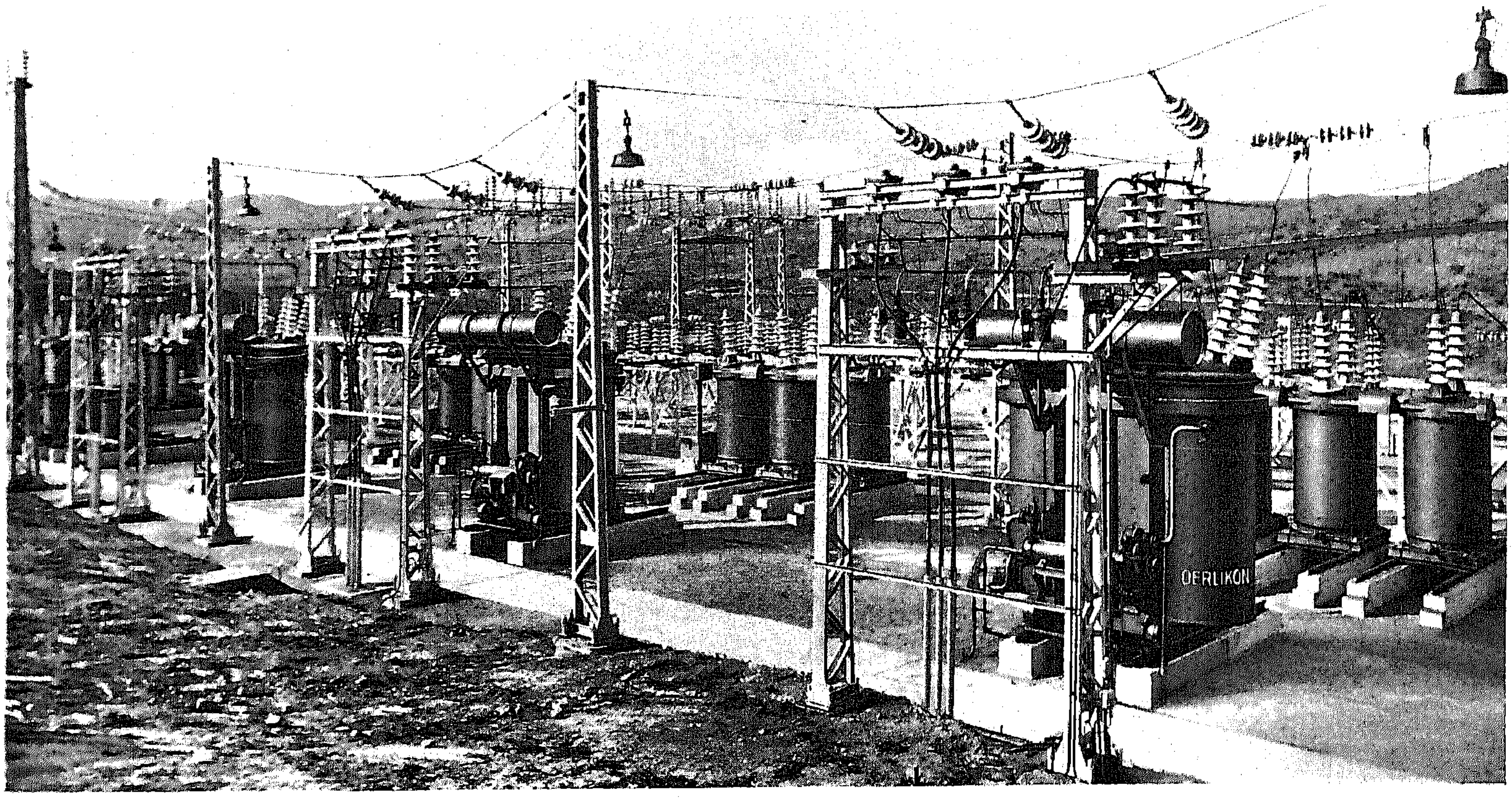
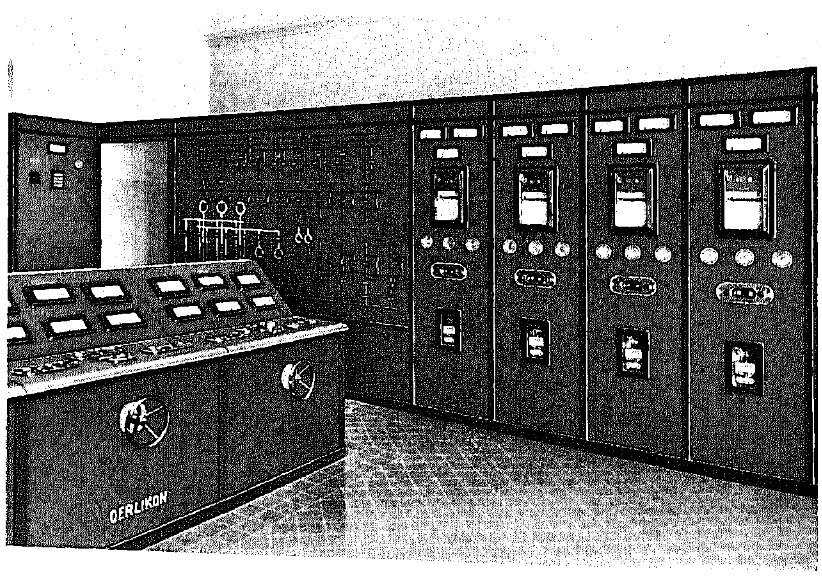


Fig. 6. Partial view of the Puente Nuevo 112.5 KV outdoor installation (in front, three main transformers).

at 110 KV. Particulars regarding the design of this gear were given in Oerlikon Bulletin No. 95 (May 1929) where the matter is dealt with in detail. The circuit breakers can be operated by hand as well as by means of motor remote control. The motor is coupled to the operating gear through the intermediary of an electro-magnetic coupling, the coil of the latter being connected in series with the motor circuit. In view of this, the operating gear is freed as soon as the coupling ceases to act as a result of the pressure of the motor failing during the switching in process or dropping to an excessive degree, and the circuit breaker returns immediately to the „off" position; as, on the other hand, the electro-magnetic coupling is not excited during the switching off process, the motor itself is not affected by the return motion of the operating gear.

The 5.6 KV auxiliary busbars can be connected at will to any desired generator by means of an oil circuit breaker, provided one generator always works on the busbars. These busbars serve for the local supply and for the distribution system at medium pressure. A 16 KV system fed by two 1000 KVA transformers for 5.6 16 KV serves for the supply of the immediate neighbourhood. An induction regulator is connected between these transformers and the busbars. This induction regulator has an external output of 2000 KVA and an internal output of 540 KVA (1931 extension); it serves for the automatic regulation of the pressure of the outgoing lines. The regulator is mounted in the open; its range of regulation amounts to 1400 volts, from 4400 volts to 5800 volts.

The supply of those of the distant distribution systems in the case of which it would not pay to run a 110 KV line, is ensured at a medium pressure of 35 KV. The two transformers which are for outdoor mounting are designed as regulating transformers with built-on step switches. These transformers have a capacity of 2000 KVA and a pressure ratio of 4400/33,000 to 38,000 volts, with a range of regulation of 5800 volts, from 33,000 to 38,000 volts, in 20 steps. The design of these step transformers has already been described in Oerlikon Bulletin No. 115 (January 1931). The step switch can be operated either by hand or by means of motor remote control. Provisions have been made for the parallel operation of the two switches in that the master switch of one step switch closes also the control circuit of the other step switch when the two transformers are working in parallel. A combination of relays causes the locking of gear in the event of



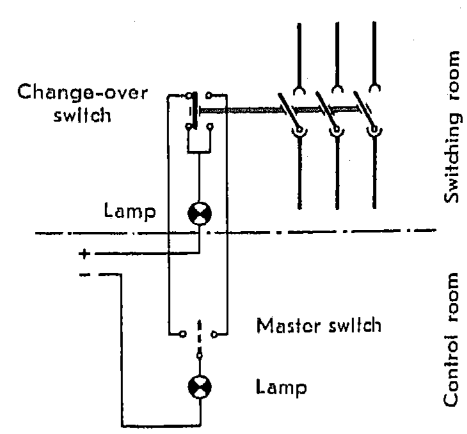


Fig. 8.

Fig. 7. Partial view of the control room.

disturbances, while at the same time an alarm bell is brought into operation. The 35 KV outdoor installation consists of two transformer equipments and of the two line equipments with single busbar system. The 35 KV oil circuit breakers which have a rupturing capacity of 200,000 KVA are triple-tank circuit breakers; they are similar as regards design to the 110 KV circuit breakers.

The control room (see Fig. 7) contains all the necessary checking, operating, measuring and regulating devices required for the reliable operation of installation; they are mounted on a switch desk and on two switchboards comprising 22 panels in all. The supervisory gear further includes, in addition to the distance thermometers of the resistance type which permit of a very thorough checking of the temperature, a mimic busbar system. This mimic busbar system is provided with miniature switches of the special Oerlikon design which are connected as shown in Fig. 8. These switches embody a pilot lamp in series with a lamp fitted on the corresponding apparatus and controlled by a change-over switch on the latter. The switching arrangement is such that the lamps are alight when the position of the miniature switch does not agree with the position of the apparatus. It is thus possible for the switchboard attendant to try the connections of the mimic busbar system, and make sure that they are correct, before making any alteration in the connections. The isolating switches in the switchgear installation can then be operated by any unskilled man, who has merely to actuate any apparatus where a pilot lamp is burning.

The generators are not only protected by the usual current and pressure relays, but they are also provided with Oerlikon-Santuari quick de-energising device. For this purpose, provision is made for a remote controlled single-pole switch, in the excitation circuit, which diverts the excitation current, through a short-circuiting resistance, in the event of danger for the generator, and then reduces the pressure instantly to zero. This arrangement is described in Oerlikon Bulletin Nos. 105, 6, so that we shall not deal with it further here.

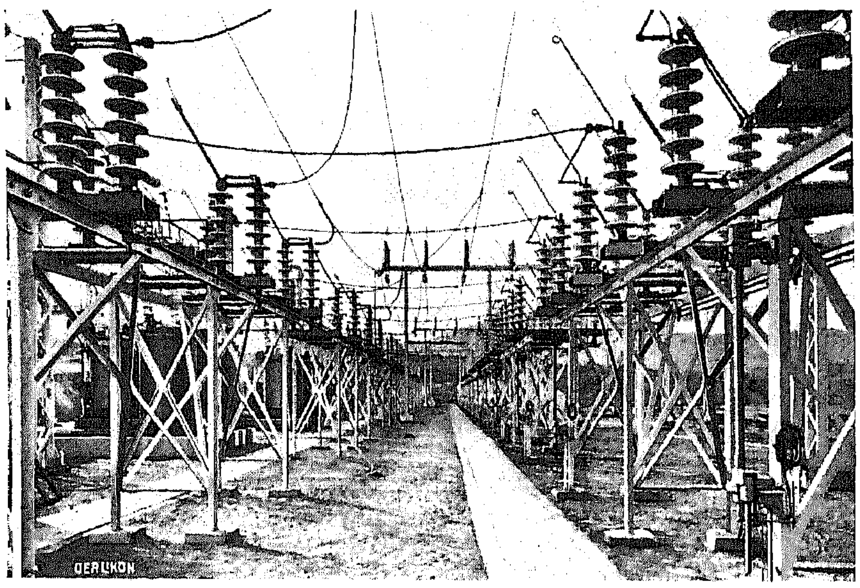


Fig. 9. Distribution isolating switches for the three busbar systems.

A room adjoining the control room contains the control panels for the station supply, and also for the motor generator set, for charging the two batteries. The main battery has a capacity of 162 ampere-hours, and supplies the current required for the various circuits of the remote control gear, of the signalling devices and of the emergency lighting at 125 volts. A small battery serves exclusively for the „Telefunken" service telephone.

A water resistance is provided at Puente Nuevo for testing purposes, and for checking operations. It is fitted with plates connected in groups of three, so as to form a complete unit. The plates are stationary; the load is adjusted by varying the level of water by means of a movable gate. The gate is arranged for hand operation and remote control, from the control room. The water resistance can absorb an output of 15,000 KW with a specific resistance of water of 6250 ohms/cm³.

(To be continued.)

The Parasitic Forces in Induction Machines. Part II.

It is probable that the vibrating radial forces are those mainly responsible for the production of noise in electric machines; they act on the stator and the casing, which have an aptitude to vibrate and propagate the noise. We propose to examine these forces more in detail. Squaring the equation 22 will give: an infinite series, whose members are the squares of the members of equation 22, and furthermore an other infinite series, whose members are all the products of two different members of equation 22 (indicated by μ and ν):

$$p_r = \frac{1}{8\pi}\Big[\Sigma B_\mu^2 \sin^2(p\mu\xi - \omega_\mu t + \varphi_\mu) + 2\,\Sigma\Sigma B_\nu B_\mu \sin(p\mu\xi - \omega_\mu t + \varphi_\mu)\sin(p\nu\xi - \omega_\nu t + \varphi_\nu)\Big] \quad \text{dyne/cm}^2 \qquad (25)$$

If we convert this expression by means of the formulae:

$$\sin^2\alpha = \frac{1}{2}(1 - \cos 2\alpha) \qquad (26)$$

$$\sin\alpha \sin\beta = \frac{1}{2}[\cos(\alpha - \beta) - \cos(\alpha + \beta)] \qquad (27)$$

we obtain:

$$p_r = \frac{1}{16\pi}\Big\{\Sigma B_\mu^2 - \Sigma B_\mu^2 \cos(2\mu p\xi - 2\omega_\mu t + 2\varphi_\mu) - 2\,\Sigma\Sigma B_\nu B_\mu \cos\big[(\mu+\nu)p\xi - (\omega_\mu + \omega_\nu)t + (\varphi_\mu + \varphi_\nu)\big] + 2\,\Sigma\Sigma B_\nu B_\mu \cos\big[(\mu-\nu)p\xi - (\omega_\mu - \omega_\nu)t + (\varphi_\mu - \varphi_\nu)\big]\Big\} \quad \text{dyne/cm}^2 \qquad (28)$$

Each pair of field harmonics give rise to mechanical forces, the order of these forces being given by the expressions in Table 4. There is a similar law governing the cyclic frequencies.

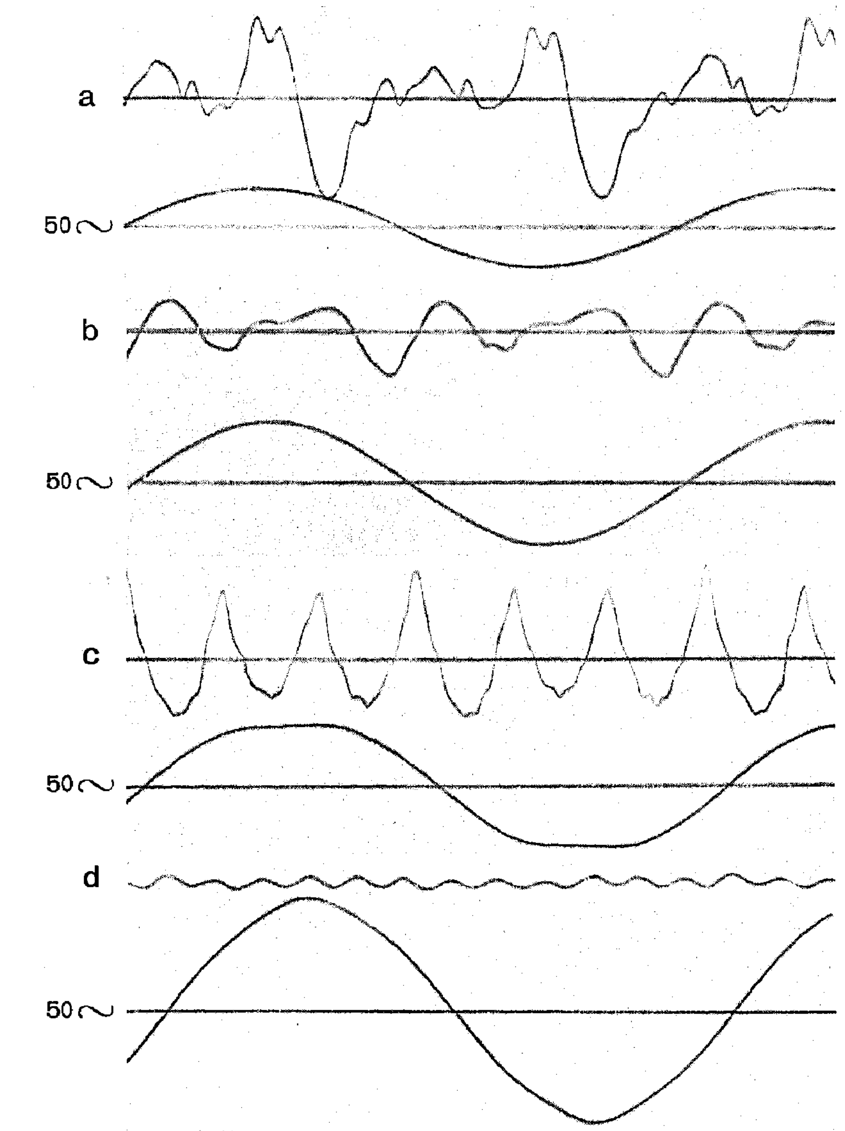


Fig. 8a, b, c and d. Vibrations of the casing of different induction motors with open rotor winding, stator winding connected to the system, at standstill.

Table 4.

Field harmonics	Force	
ν	0*),2 ν	$\mu+\nu, \mu-\nu$
μ	0*),2 μ	

*) Constant force distributed uniformly along the periphery.

Example: Let us take the case where an induction regulator or a stationary induction motor is connected to the system. If the permeability of the iron is equal to infinity, all magnetic fields (fundamental field, field harmonics of the windings and slots) would revolve at the frequency of system. As a result of the saturation of the iron, there are, however, saturation field harmonics with a cyclic frequency (3, 5, 7, ...) ω. The strongest field harmonic is that of third order. According to equation 28 or Table 4 there arise from the strong third harmonic and the fundamental field, forces with cyclic frequencies 0, 2 ω, 4 ω, 6 ω. Furthermore, there are oscillations, in all the even harmonics of the system frequency, due to the even higher saturation field harmonics. In Fig. 8, we have reproduced oscillograms of the vibrations of the casing of various stationary magnetised three-phase motors with open rotor winding (taken with the „Shaker" microphone). The second and fourth harmonics of the frequency of system can be clearly seen in the vibrations in Figs. 8a and b, the sixth in Fig. 8c and the twelfth in Fig. 8d.

The equation 28 comprises four members. The first corresponds to a constant force distributed evenly along the periphery; the other three represent oscillating forces distributed sinusoidally, which latter forces cause the rotor and stator to vibrate and may produce noise. We propose to examine under what conditions these forces become dangerous. The last member of the equation 28 is:

$$p_{r,4} = \frac{1}{8\pi} \Sigma\Sigma\, B_\mu B_\nu \cos\left[(\mu-\nu)\, p\, \xi - (\omega_\mu - \omega_\nu)\, t + (\varphi_\mu - \varphi_\nu)\right] \text{ dyne/cm}^2 \qquad (29)$$

and represents a sum of radial tractive efforts, each of which is distributed sinusoidally along the periphery with a periodicity in space $\Delta p = p\ (\mu-\nu)$ cycles. The following cases can occur:

a) $\Delta p = (\mu-\nu)\ p = 0$. Two field harmonics have the same number of poles. The equation 29 becomes:

$$p_{r,4} = \frac{1}{8\pi} B_\mu B_\nu \cos\left[(\omega_\mu - \omega_\nu)\, t - (\varphi_\mu - \varphi_\nu)\right] \text{dyne/cm}^2 \quad (30)$$

There is a vibrating force evenly distributed along the periphery, but with a cyclic frequency $(\omega_\mu - \omega_\nu)$. The amplitude of the total concentric radial force is:

$$P_r = l\,R \int_0^{2\pi} p_{r,4}\, d\xi = \frac{l\,R}{4} B_\mu B_\nu \quad \text{dyne} \qquad (31)$$

$$P_r \doteq \frac{l\,R}{4} B_\mu B_\nu \times 10^{-6} \text{ kg} \qquad (32)$$

This force makes the stator, the rotor and the casing vibrate like a pipe subjected to a vibrating pressure.

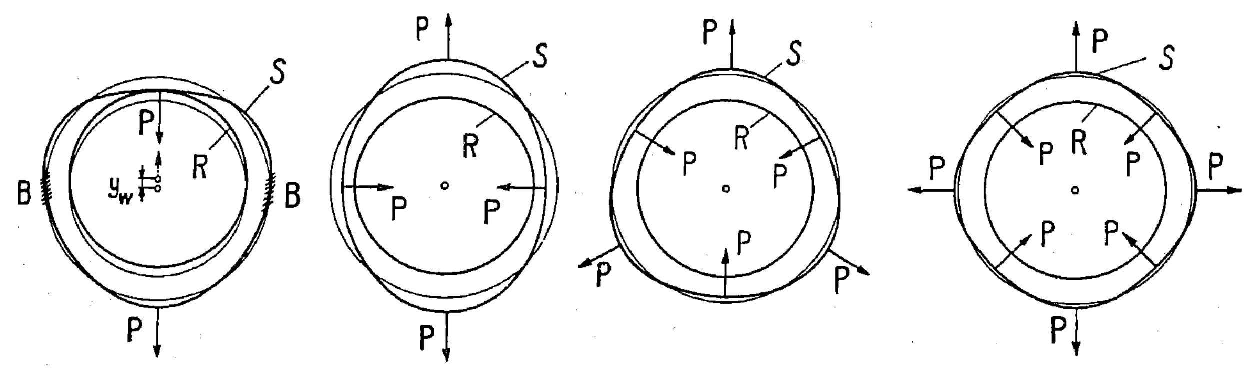


Fig. 9. Diagrammatical representation of the stresses and resulting deformations in a stator ring due to forces distributed sinusoidally on the periphery with: a) $\Delta p = 1$, b) $\Delta p = 2$, c) $\Delta p = 3$, d) $\Delta p = 4$ waves. S = Stator, R = Rotor, P = Force, B = Fastening of stator, Y_w = Deflection of shaft.

b) $\Delta p = p\ (\mu-\nu) = 1, 2, 3 \ldots$. Two field harmonics have a small difference in pairs of poles. It can be seen from equation 29 that there is a force distributed sinusoidally along the periphery with a periodicity in space $\Delta p = p\ (\mu-\nu)$ cycles and with a cyclic frequency $(\omega_\mu - \omega_\nu)$. We have represented diagrammatically, in Fig. 9, the forces for $\Delta p = 1, 2, 3, 4$ and the deformations which they create in the stator.

For $\Delta_p = 1$, the radial forces produce an eccentric resultant; the value of this resultant which can be easily determined is:

$$P_e = \frac{l\,R}{8} B_\nu\, B_\mu \,\text{dyne} \doteq \frac{l\,R}{8} B_\nu\, B_\mu \times 10^{-6}\,\text{kg} \qquad (33)$$

This revolving eccentric force can, in the event of resonance with the natural frequency of oscillation of the shaft, cause the rotor to vibrate so heavily that it comes into contact with the stator, with the result that friction occurs and a depression is produced in the torque curve, such as represented in Fig. 1c [10]). These depressions, unlike those of the curves of the asynchronous and synchronous type, occur in most cases at the higher speeds (for instance, at 45, 70% synchronous speed). Of course, noise is produced at the same time by the vibrations.

In the case of $\Delta_p = 2$ [11]), 3, 4..., there is actually no eccentric force, but the deformations of the stator ring are relatively large for this distribution of forces; this deformation increases with decreasing number of waves of the force along the periphery.

If we compare by way of calculation and experiment the deformations produced, in case a) and case b), we find that the forces distributed in space with a small number of cycles (case b) produce larger deformations than the force evenly distributed along the periphery (case a). In view of this, small differences in pairs of poles of field harmonics are more dangerous than equality of pairs of these fields.

Number of slots in the case of which there are dangerous radial forces.

The choice of the number of slots of the stator and rotor only decisively influences the fourth member of the equation 28 ($p_{r,4}$ see also equation 29). The differences in pairs of poles of the field harmonics (Δ_p), fix the distribution of these forces along the periphery and, consequently, the strength of the vibrations produced. The second and third member of the equation 28 is only little influenced by the choice of the number of slots, and the corresponding forces are unavoidable in any motor; they are, however, less dangerous, as they are, in most cases, distributed in space with a large number of cycles and thus produce smaller deformations. The number of slots must therefore be chosen mainly with regard to the fourth member of the equation 28.

The winding and slot field harmonics $\nu = \frac{N}{p} \pm 1$ are especially dangerous, in view of the fact that their amplitudes are relatively large (see also Section III) and the frequency of the forces produced is high and thus apt to cause loud noises.

a) Equality of pairs of poles of these strong field harmonics is obtained when: $\frac{N_1}{p} \pm 1 = \frac{N_2}{p} \pm 1$ (34)

thus: $N_2 - N_1 = 0, \pm 2p$ (35)

These differences in slots are also dangerous for the reason that they cause parasitic forces (see Section IV, 2 B), and must be avoided.

The higher harmonics $\nu = c\frac{N}{p} \pm 1$ (see equation 12) are often sufficiently strong to cause noise, so that even:

$$c_1 \frac{N_1}{p} \pm 1 = c_2 \frac{N_2}{p} \pm 1 \qquad (36)$$

at least for $c_1, c_2 \leqq 2$ is to be avoided.

Slipring motors with standard symmetrical windings with full number of slots per pole and phase and same number of phases in stator and rotor, have series of field harmonics of the same order in the stator and rotor. Apart from the fifth and seventh field harmonic, there are normally no strong field harmonics of the same order. In the case of large openings of slots and full utilisation, considerable noise can, however, be produced. Also current harmonics cause vibration and noise in slipring motors.

b) A small difference in pairs of poles of the field harmonics is, as already mentioned, more dangerous than equality of pairs of poles. Numbers of slots, in the case of which the strong stator and rotor fields of $\left(\frac{N}{p} \pm 1\right)^{th}$ order have a small difference in pairs of poles, say $\Delta_p = 1, 2$ to 3, are therefore bad numbers of slots and give rise, in most cases, to noise.

Numerous instances, in practice, have demonstrated the correctness of this criterium. We give below a few such instances.

Table 5. Bad number of slots.

$\Delta_p = p(\mu - \nu)$	2p	N_1	N_2	Dangerous field harmonics Stator $p\mu$	Rotor $p\nu$
± 1	4	36	33	34	35
	6	36	41	39	38
± 2	4	36	34	38	36
	6	36	40	39	37
± 3	6	54	57	51 57	54 60
	8	48	45	44 52	41 49

Frequencies of noise.

The frequencies of noise, which are produced by the radial forces, can be calculated by means of the equation 28 and Table 4.

The cyclic frequency of the stator, winding and slot field harmonics is $\pm\omega$ (= cyclic frequency of system: ± according to the direction of rotation). The cyclic frequency of rotor field harmonics can be derived from the equations 16 or 18. The rotor field harmonics of $\left(\frac{N_2}{p} \pm 1\right)^{th}$ order which give with a stator field harmonic a difference in pairs of poles $\Delta_p = 0, 1, 2, 3\ldots$, cause, for instance, when the rotor is running synchronously, the following cyclic frequency of the radial force and, consequently, of the noise:

$$\omega_k = \omega\left[\frac{N_2}{p} \pm 1 - (\pm 1)\right] = \left(\frac{N_2}{p}, \frac{N_2}{p} \pm 2\right)\omega \qquad (37)$$

The frequencies (f) have a magnitude of about 600 to

10) Fritze was the first to draw attention to these eccentric forces and to their effect. „Production of Noise in Electric Machines", Arch. El., Vol. 10 (1921), page 73.

11) The author has drawn attention to the case $\Delta_p = 2$ in an internal report of the Oerlikon Company (July 1929) and given the corresponding bad numbers of slots. There appeared later in the J. A. I. E. E., Vol. 49 (1930), page 7, an article by Hildebrandt entitled „Quiet Induction Motors" where the effect of two field harmonics with a difference in pairs of poles $\Delta_p = 2$ was equally dealt with.

3000 cycles; they are therefore within the range of good audibility (see Fig. 4).

Example: a) The motor considered in Section III, with $m_1 = 3$, $2p = 4$, $N_1 = 24$, $N_2 = 27$ has field harmonics such as given in Table 3. The stator field of 13^{th} order and the rotor field of 12.5^{th} order have a difference in pairs of poles $\Delta p = 1$. The dimensions of the armature are $R = 10$ cm; $l = 10$ cm; the eccentric force under short-circuit conditions, is then, according to equation 33, about 1400 Kgs. At rating load, this force has only a value of about 22 Kgs. Its cyclic frequency is (equation 37) $\omega_k \doteq 11.5\,\omega$ and the frequency of the corresponding noise component is $11.5 \times 50 = 575$ cycles.

b) Oscillograms were taken of the vibrations and noise of a squirrel cage motor $2p = 6$, with the bad numbers of slots $N_1 = 54$; $N_2 = 57$ (see Table 5), at no-load (Fig. 10). The 19^{th} harmonic of the frequency of system can be seen very clearly both in the vibrations and the noise. According to the theoretical deductions, there are the following strong field harmonics: Stator $\nu = 17, 19$; Rotor $\mu = 18, 20$. The pairs of field harmonics ($\nu = 17; \mu = 18$) and ($\nu = 19; \mu = 20$) create a force with a periodicity in space $\Delta p = 3$ and with a cyclic frequency $19\,\omega$. There are also a number of current harmonics in the rotor which produce forces of the same frequency.

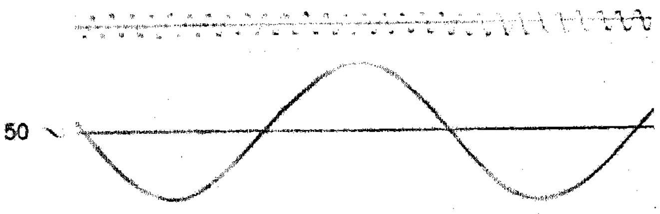


Fig. 10a. Vibrations of the casing (recorded by means of the „shaker" microphone);

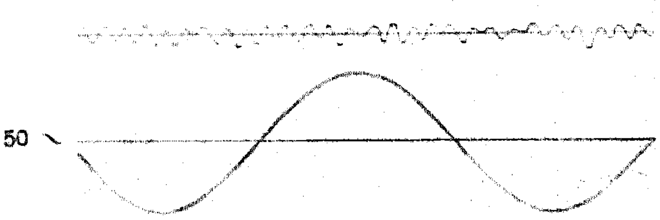


Fig. 10b. Noise (recorded by means of the carbon microphone) of a three-phase squirrel cage motor, $2p = 6$, $N_1 = 54$, $N_2 = 57$, at no-load.

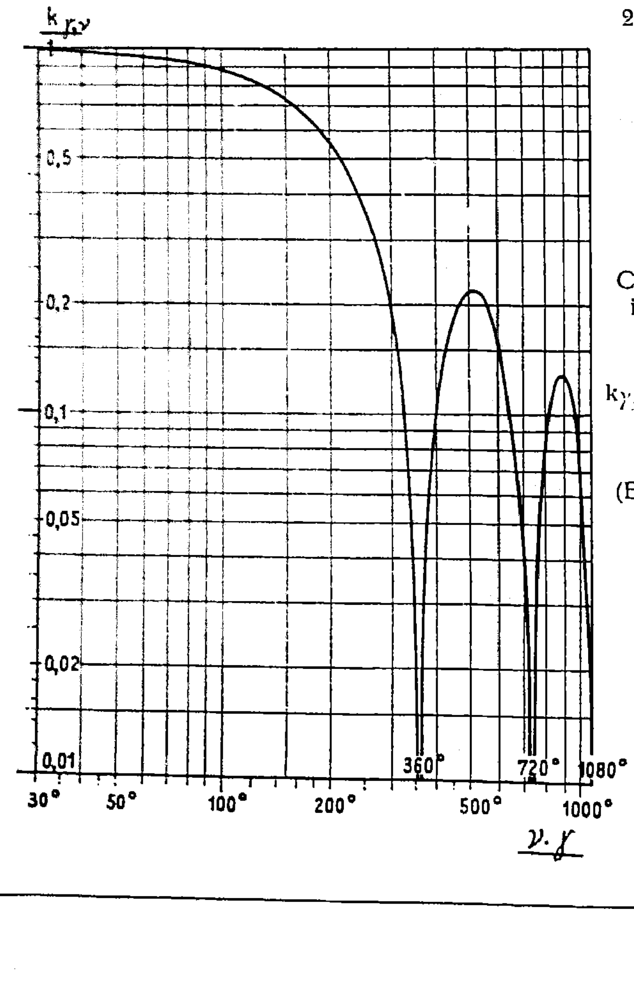


Fig. 11. Coefficient of inclination:

$$k_{\gamma,\nu} = \frac{\sin \frac{\nu\gamma}{2}}{\frac{\nu\gamma}{2}}$$

(Equation 38).

Slots with an oblique direction.

It is possible to obtain, by giving an oblique direction to the slots, a phase displacement of the radial forces along the iron core; forces with the same magnitude are distributed on the helical paths of the cylindrical stator bore. The force totalled along a surface line (equation 28, members 2–4) is reduced by the factor:

$$k_{\gamma,\nu} = \frac{\sin \frac{\nu\gamma}{2}}{\frac{\nu\gamma}{2}} \qquad (38)$$

where γ is the electrical angle (referred to the fundamental field) through which the two ends of slots are displaced in relation to each other and ν is the order of the field harmonic of the oblique (stator or rotor) slots. The factor $k_{\gamma,\nu}$ is plotted in Fig. 11. When the slant of the slots is $\gamma = \frac{2\pi}{\nu}$, the totalled force along a surface line of the stator bore is itself zero, but the local forces remain and can create local vibrations, specially when the core is wide and subdivided into packets.

In most cases, the detrimental effect of bad numbers of slots causing radial forces cannot be entirely eradicated by giving the slots a slant.

One-sided forces caused by eccentricity.

This question has been dealt with exhaustively by Rosenberg[12]). We obtain, of course, the same results as Rosenberg if we resolve the magnetic fields into harmonics. For the sake of briefness, we propose only to summarise the results here.

When the shaft occupies an eccentric position in the stator bore, this gives rise to a constant eccentric force stationary in relation to the stator which causes the shaft to bend.

Rosenberg has given an accurate method for calculating the one-sided forces. The following formula is sufficient for a rough calculation:

$$P_e = \frac{l\,R}{8} B^2\,\varepsilon \text{ dyne} \doteq \frac{l\,R}{8} B^2\,\varepsilon \times 10^{-6} \text{ kg} \qquad (39)$$

($\varepsilon = \frac{e}{\delta}$ is the relative eccentricity of the rotor).

This approximate formula gives fairly exact results for lightly saturated machines and small eccentricities.

If the rotor is mounted eccentrically on the shaft, the eccentric force revolves with the angular speed of the shaft.

The eccentric forces can reach very high values; it is, therefore, necessary to maintain carefully a concentric position. It is also advisable to provide for a number of parallel branches of the winding (see Rosenberg).

Example: Diameter of bore 100 cm, width of core 30 cm, density of field 7000 Gauss, eccentricity 10%. If we leave out of account the saturation, the eccentric force is, according to equation 39, about 1000 Kgs. If the eccentricity is produced by the eccentric position of the rotor on the shaft, the eccentric force revolves. At 1500 rpm. the frequency of the vibrations is 25 cycles.

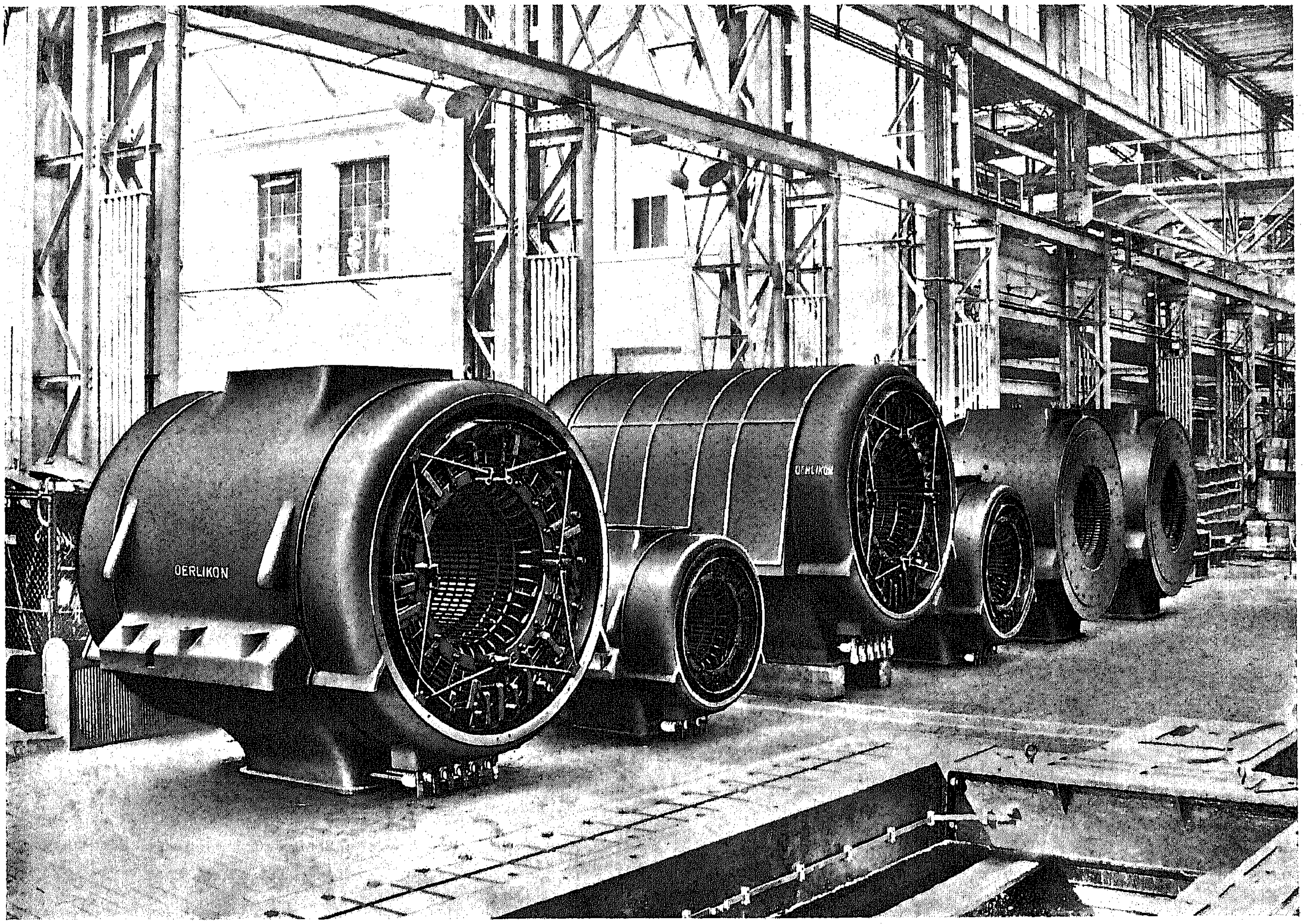
(To be continued.)

[12]) Rosenberg „One-sided tractive effort in electric machines". E. & M., Vol. 35 (1917), pages 525, 539.

BULLETIN OERLIKON

No. 126 — December 1931

Contents: Some notable OERLIKON turbo-generators.
The parasitic forces in induction machines. Part III (Concluded).



STATORS OF THREE-PHASE TURBO-GENERATORS
IN THE PROCESS OF BEING ASSEMBLED IN THE SHOPS OF THE OERLIKON COMPANY.

From left to right, stators built to the following data, respectively:
25000 KVA — 10000-11000 Volts — 50 Cycles — 3000 RPM. (Hamma Power Station, Algiers)
3750 KVA — 13200 Volts — 60 Cycles — 3600 RPM. (City of Lethbridge, Canada)
40000 KVA — 5200- 5700 Volts — 50 Cycles — 3000 RPM. (Sequedin Power Station, Lille)
7500 KVA — 10000-11000 Volts — 50 Cycles — 3000 RPM. (Alexandria Power Station, Egypt)
and, on the extreme right, two stators without windings for 25000 KVA generators (Groningen, Holland and Mines d'Anzin, Thiers Power Station).

See also article entitled „Some Notable OERLIKON Turbo-Generators", on last page.

The Parasitic Forces in Induction Machines. Part III (Concluded).

2) The tangential forces.

The equation 24 for the tangential stresses, such as obtained at the beginning of Section IV by applying the Biot-Savart Law, can, as in the case of the equation 25 for the radial stresses, be converted by means of the trigonometrical equations 26 and 27 into the following expression:

$$p_t = \frac{1}{20}\left\{ \Sigma\Sigma B_\mu A_\nu \cos\left[(\mu-\nu)p\xi-(\omega_\mu-\omega_\nu)t+(\varphi_\mu-\varphi_\nu)\right] + \Sigma\Sigma B_\mu A_\nu \cos\left[(\mu+\nu)p\xi-(\omega_\mu+\omega_\nu)t+(\varphi_\mu+\varphi_\nu)\right]\right\} \text{ dyne/cm}^2 \quad (40)$$

Each field harmonic and current distribution harmonic gives, as we see, two tangential forces distributed sinusoidally along the periphery with $(\mu \pm \nu)$ waves and with the cyclic frequencies $\omega_\mu \pm \omega_\nu$. In any induction machine, there is unavoidably a large number of such forces which act on the teeth of the stator and rotor. It would seem, however, that the tangential forces, which are anyhow weaker than the radial forces, are in general not very dangerous with regard to production of noise, as on the one hand the vibrations of the teeth are heavily damped by the filling of slots and, on the other hand, the vibrating surfaces, that is to say, the faces of teeth, do not radiate the sound waves well.

As a rule, the only stresses that are of interest are those, which integrated along the whole periphery give a resultant force and thus create a torque. This case can, however, only arise when $\nu = \mu$, that is to say, when the stress represented by the first member of equation 40 is distributed with zero cycles in space, i. e. uniformly, along the periphery. The resultant force is then:

$$p_{t,\nu} = \frac{\pi R l}{10} B_\mu A_\nu \cos\left[(\varphi_\mu-\varphi_\nu)-(\omega_\mu-\omega_\nu)t\right] \text{ dyne} \quad (41)$$

and the torque:

$$D_\nu = \frac{\pi R^2 l}{10} B_\mu A_\nu \cos\left[(\varphi_\mu-\varphi_\nu)-(\omega_\mu-\omega_\nu)t\right] \text{ dyne cm} \quad (42)$$

When $\omega_\mu \lessgtr \omega_\nu$ we have a pulsating torque somewhat similar to that encountered in a synchronous machine working with a slip. When $\omega_\mu = \omega_\nu$ we have a constant torque reaching a maximum for $\varphi_\mu - \varphi_\nu = 0$. The value of torque is then:

$$D_\nu = \frac{\pi R^2 l}{10} B_\mu A_\nu \text{ dyne cm} \quad (43)$$

or

$$D_\nu = \frac{\omega \pi R^2 l}{p} B_\mu A_\nu \times 10^{-8} \text{ syn. watts} \quad (44)$$

We can still differentiate between the cases where the current distribution represented by the quantity A_ν in the equations 43 and 44 is caused by the pressure induced by the field B_μ, and where it is produced by another pressure. In the first case, we have a torque similar to that in an asynchronous machine (asynchronous parasitic torque, Fig. 1a); in the second case, the torque is as that of a synchronous machine (synchronous parasitic torque, Fig. 1b).

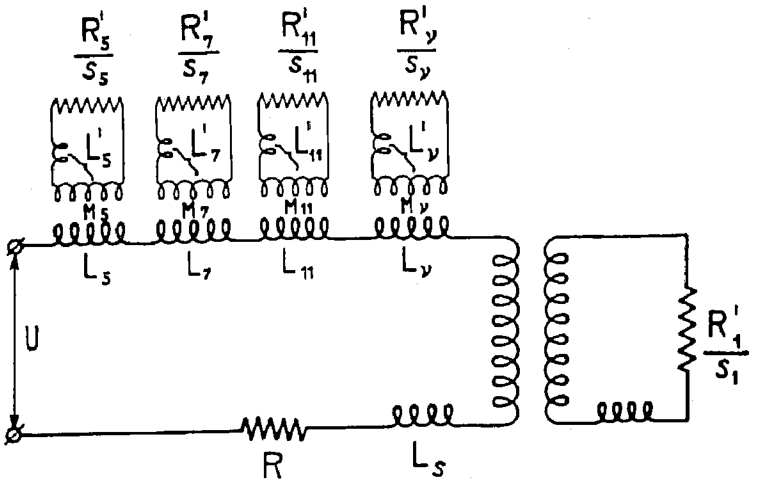


Fig. 12. Equivalent circuit of a squirrel cage motor. Representation of the electromagnetic linkage of the stator field harmonics [14]).

A) Asynchronous parasitic torques. [13])

The classical theory of induction machines only takes into account the mutual induction of the stator and rotor winding arising from the fundamental fields. As regards the field harmonics of the stator (rotor), the assumption is made that they do not have any inductive effect at all on the rotor (stator) winding, and that they only induce in their own winding a stray E. M. F. (E. M. F. of the differential, doubly interlinked leakage). This simplification is no longer permissible when calculating the parasitic torques, and we have to take into account the mutual induction of the stator and rotor windings, in the case of the field harmonics, too.

The equivalent diagram in Fig. 12 is intended to show how the asynchronous parasitic torques occur in squirrel cage motors [14]). An interlinking of the stator winding with the squirrel cage winding, in the manner of a transformer, is represented for each field harmonic of the stator field. All these interlinked circuits carry the stator current; we can imagine the whole system as being the connecting up in series of the „fundamental field motor“ developing the useful torque and of a series of „field harmonic motors“. As will be explained hereafter more in detail, the rotor field harmonics create in the stator phase winding very small torques. For this reason, no „field harmonic motors“ have been introduced in the rotor circuit of the equivalent diagram in Fig. 12. Field harmonics due to the slots produce, when starting, much smaller torques than the winding harmonics (see further); the action of these slot harmonics is likewise not shown in the equivalent diagram. Their effect will, however, be subsequently allowed for by applying a correction.

Each „field harmonic motor“ is entirely determined by the following constants:

a) by the self-induction coefficient L_ν which covers the interlinking of the stator winding with the ν^{th} field harmonic. Assuming that the permeability of the iron is infinity, the coef-

[13]) The contents of this section were published by the author in part, in 1929: Krondl, „The parasitic torques in induction machines“, Elektrotechnicky Obzor 1929, pages 225, 248, 262, 280.

[14]) According to Andronescu, „On the mode of variation of the torque of squirrel cage induction motors“, Arch. El., Vol. 12 (1923), page 453.

ficient L_ν can be easily derived from the self-induction coefficient of the fundamental field, which is supposed to be known:

$$L_\nu = L_1 \left(\frac{k_\nu}{k_1 \nu}\right)^2 \qquad (45)$$

or

$$\omega L_\nu = X_{1,0} \left(\frac{k_\nu}{k_1 \nu}\right)^2 \qquad (45a)$$

$\left(\frac{k_\nu}{k_1}\right)$ see Table 2.

It may further be recalled that we have, on the basis of the classical theory of induction motors and of the theory of differential leakage [15] [16]), the following relation for the stator differential leakage:

$$\tau_{dif,1} = \frac{\Sigma L_\nu}{L_1} - 1 \qquad (46)$$

The front and slot leakage of stator is represented by the quantity L_s in Fig. 12.

b) by the Blondel leakage coefficient:

$$\tau_{\nu,B} = \frac{L_\nu L'_\nu}{M_\nu^2} - 1 \qquad (47)$$

or still better by the coupling factor:

$$\varkappa_\nu = \frac{M_\nu^2}{L_\nu L'_\nu} = \frac{1}{1+\tau_{\nu,B}} \qquad (48)$$

of the corresponding ν^{th} „field harmonic motor". L'_ν is the secondary self induction coefficient of this motor and covers the interlinking with all fields produced by the current harmonic induced by the ν^{th} field harmonic in the squirrel cage winding (for particulars regarding calculation of $\varkappa_\nu$, see below).

c) by the ohmic resistance R_ν offered by the squirrel cage winding to the ν^{th} current harmonic.

The maximum value of the torque of each of these „field harmonic motors" can be derived from a circle diagram, defined by the above constants. As the maximum of the torque occurs at quite low speeds, we can take approximately the short-circuit current of the motor as current flowing through the primary portion of the „field harmonic motors" connected in series. If we plot the impedance or pressure diagram, the maximum watt component of pressure obtained from this diagram corresponds to the maximum torque. This maximum watt component of pressure can be derived from the circle diagram on the basis of simple geometrical laws (Fig. 13):

$$U_{w,\nu} = U_{0,\nu} \frac{\varkappa_\nu}{2} \qquad (49)$$

$U_{0,\nu}$ is the no-load pressure we have at synchronism of the ν^{th} harmonic field:

$$U_{0,\nu} = \omega L_\nu I_k \qquad (50)$$

The maximum torque is thus:

$$D_\nu = \frac{m_1 U_{w,\nu} \; I_k \times 10^7}{\frac{\omega}{\nu p}} \text{ dyne cm} \qquad (51)$$

It is better, however, to express the torque in „synchronous" watts (referred to the synchronous speed of the fundamental field).

$$D_\nu = \frac{m_1 U_{w,\nu} \; I_k}{\frac{\omega}{\nu p}} \; \frac{\omega}{p} = m_1 U_{w,\nu} I_k \nu \text{ syn. watts} \qquad (52)$$

If we introduce equations 49 and 50 in equation 52, we have:

$$D_\nu = \frac{m_1}{2} \omega L_\nu I_k^2 \varkappa_\nu \nu \text{ syn. watts} \qquad (53)$$

The only quantity upon which the maximum parasitic torque is dependent, apart from the short-circuit current, is the inductive coefficient and coupling factor, and there is no need to calculate the resistance R_ν.

Calculation of the coupling factor $\varkappa_\nu$.

As a result of the high iron saturation under short-circuit conditions, the self-induction coefficient L_ν and the coupling factor $\varkappa_\nu$ cannot be determined with certainty. We propose, however, to consider the theoretical formulae for the case where the permeability is infinity, as these formulae supply data which are useful in practice, at least from a qualitative point of view. The Blondel leakage coefficient in equations 47 and 48 is, as we know:

$$\tau_{\nu,B} = \tau_\nu + \tau'_\nu + \tau_\nu \tau'_\nu \qquad (54)$$

τ_ν (τ'_ν) is the leakage coefficient for the primary (secondary) side of the ν^{th} „field harmonic motor". As we have assumed that the primary self-induction coefficient of this motor only covers the ν^{th} field harmonic, we have, on the basis of the theory of differential leakage $\tau_\nu = 0$ and, consequently (see equation 54):

$$\tau_{\nu,B} = \tau'_\nu \qquad (55)$$

The secondary leakage coefficient τ'_ν is made up of the coefficients of the differential, slot and front leakage, which can be calculated by means of the well known formulae. It is

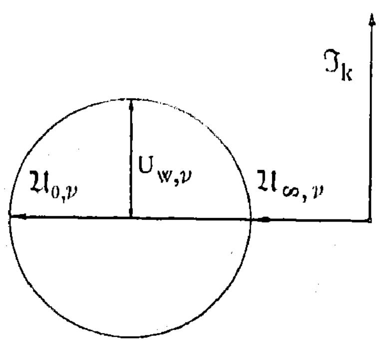


Fig. 13. Voltage circle diagram of a polyphase induction motor.

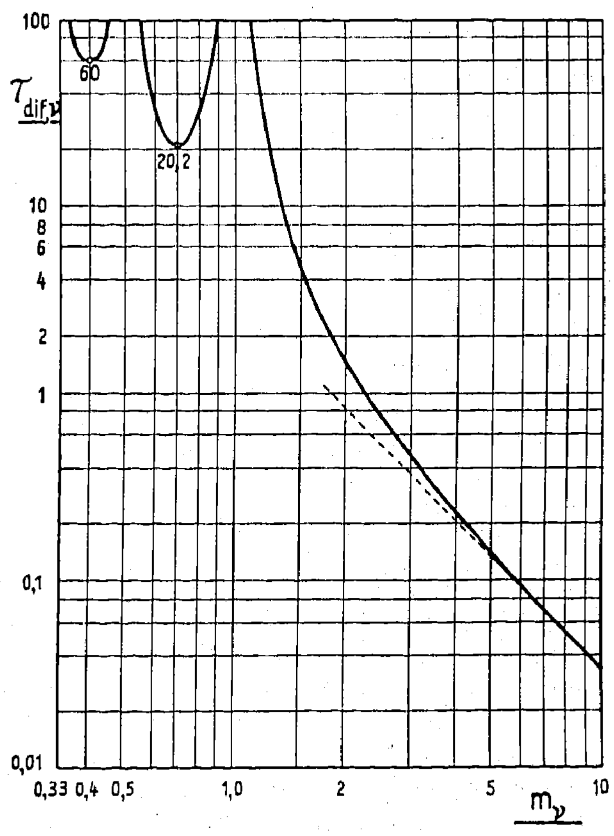
$$U_{\infty,\nu} = U_{0,\nu} \frac{\tau_\nu}{1+\tau_\nu}$$

(see equation 49).

Fig. 14. Differential leakage of a squirrel cage motor.

$$\tau_{dif,\nu} = \left(\frac{\frac{\pi}{m_\nu}}{\sin \frac{\pi}{m_\nu}}\right)^2 - 1$$

(Equation 56)



[15]) Dreyfus, „On the doubly interlinked leakage of three-phase motors" E. u. M., Vol. 37 (1919), page 149.

[16]) Krondl, „Differential leakage", Elektrotechnicky Obzor 1926, page 255; „Differential leakage in induction machines" R. G. E., Vol. 23 (1928), pages 433, 479.

the differential leakage that plays the predominant part. In the case of squirrel cage windings, it is given by the formula[16]):

$$\tau_{dif,\nu} = \left(\frac{\frac{\pi}{m_\nu}}{\sin \frac{\pi}{m_\nu}} \right)^2 - 1 \tag{56}$$

$m_\nu = \frac{m_2}{\nu} = \frac{N_2}{p\,\nu}$ is the number of phases of the cage for the ν^{th} field harmonic. We have plotted the quantity $\tau_{dif,\nu}$ in Fig. 14. (The coefficient of the front leakage of cage windings is a function of the number of phases m_ν similar to equation 56, while the coefficient of the slot leakage is inversely proportional to the square of the number of phases m_ν).

If we study the curve in Fig. 14 and go from the larger to the smaller values of m_ν, we see that, for $m_\nu = 1$, $\tau_{dif,\nu}$ increases rapidly towards infinity and then drops again to finite though large values. For $m_\nu = \frac{1}{2}, \frac{1}{3}, \frac{1}{4} \ldots$, it reaches again a value $\tau_{dif,\nu}$ = infinity. In view of the fact that the parasitic torque as expressed by equation 53 is proportional to the quantity $\varkappa_\nu = \frac{1}{1 + \tau_{\nu,B}}$, large torques only occur, when the value of $\tau_{\nu,B}$ is not too great, that is to say, when m_ν is considerably more than 1 (approx. for $m_\nu > 1.4$). In fact, it is known from various measurements[17]) that the dangerous $\left(\frac{N_1}{p} \pm 1\right)^{th}$ field harmonics cause a large torque only when the number of rotor slots exceeds to a certain extent that of the stator slots (approx. when $N_2 \geqq 1.4\,N_1$); this corresponds to about $m_\nu = 1.4$. A great excess in the number of rotor slots over that of the stator slots (approx. $N_2 > 1.4\,N_1$) should be avoided, especially in the case of slots that are not arranged obliquely.

The coupling factor $\varkappa_\nu$ is a continuous function of the number of phases m_ν of the cage winding (except for $m_\nu = 1, \frac{1}{2}, \frac{1}{3}, \ldots$, when it is zero). There are, therefore, insofar as asynchronous parasitic torques are concerned, no bad numbers among the numbers of rotor slots, such as are encountered for radial forces, Section IV, 1, or for synchronous parasitic torques, Section IV, 2 B; the larger the value of m_ν, the greater are the asynchronous depressions of the torque curve (strictly speaking, this applies only to the range $m_\nu > 1$).

As mentioned before, the field harmonics create no asynchronous torques or at least very small ones in phase windings. The reason for this is one of the following:

a) The winding factor of the phase winding for the corresponding field harmonic may be zero; the coupling factor is then zero too and no torque can occur at all.

Example: The cage winding $m_2 = 13.5$ (see Table 5) produces, for instance, the 12.5th and 14.5th harmonic. In both cases, the corresponding winding factor of the stator winding is zero.

b) Even when the winding factor of the phase winding is different from zero for any field harmonic, the coupling factor and, consequently, the parasitic torque is, nevertheless, small.

Example: For a three-phase winding $N_1 = 24$, $q = 2$, the coupling factors $\varkappa_\nu$ are as follow:

Table 6.

$\nu =$	5	7	11	13	17	19
$\varkappa_\nu =$	.029	.015	.082	.059	.0025	.002

(We have taken, in this connection, as total leakage coefficient for the fundamental field, $\tau_B = .11$).

The case where $m_\nu = 2$ for squirrel cage windings has been formerly regarded by other authors as a specially unfavourable one, as the cage represents a single-phase winding for the ν^{th} field harmonic. It was then assumed that, for about $\frac{n_{syn}}{\nu}$ and $\frac{n_{syn}}{2 \cdot \nu}$, heavy torques occurred (Görges phenomenon). The fundamental condition for the occurrence of the Görges phenomenon is, however, that the anti-synchronous rotating field which is due to the single-phase rotor, should be dampened by the stator winding. As, however, the phase winding of the stator has, for the field harmonic, a very heavy leakage (see, for instance, Table 6), there is only a weak damping effect, and no strong Görges phenomenon occurs for $m_\nu = 2$; consequently, the parasitic asynchronous torque has not a specially high value. We have often, for $m_\nu = 2$, very large depressions in the torque curve; these are, however, of a synchronous nature and are, furthermore, not exclusively bound to the condition $m_\nu = 2$ (for further details, see Section IV, 2 B).

The validity of the theoretical formulae for the leakage (specially the differential leakage) of squirrel cage armatures, was tested on a model of a „field harmonic motor"; at the same time, the influence of the saturation was investigated, at least for information purposes. A six-pole three-phase motor with a stator with standard winding and having 54 slots was provided with a rotor with 36 slots, in which 2, 4, 12, 36 bars were placed successively and soldered to the short-circuiting rings. The corresponding number of phases of the cages were thus: $m = {}^2/_3, {}^4/_3, 4, 12$. With $m = {}^2/_3, {}^4/_3$, the „field harmonic motors" reproduced were approximately the $\left(\frac{N}{p} \pm 1\right)^{th}$, and with $m = 4, 12$, the lowest, for instance the fifth and seventh. Measurements were made on this motor with different currents at synchronism and standstill, and, on the basis of these tests, the electromagnetic constants of the motor were determined for the different numbers of phases of cage and for the different saturations. As in the „field harmonic motors", the current flowing at synchronism of the corresponding field harmonic is approximately the same as at standstill, the same current was taken both for synchronism and for short-circuit conditions, when working out the leakage coefficients, etc., on the basis of the measurements. It is proposed to give here only a brief summary of the results of these tests which are, in fact, not yet completed: a) in the case of a low saturation, the measurements agreed with the theory, for all numbers of phases of cages measured; b) when the saturation was increased, appreciable differences were noted, these being as follows; α) in the case of large numbers of phases ($m = 4, 12$), the leakage coefficient τ_B increased with the saturation and the product $\varkappa\,\omega\,L$ (see equation 53), which is proportional to the maximum torque, decreased with it; β) in the case of smaller numbers of phases ($m = {}^2/_3, {}^4/_3$), τ_B decreased with the saturation and $\varkappa\,\omega\,L$ increased with it.

17) Stiel, „Experimental investigation of the torque of three-phase induction motors with squirrel cage rotors with different numbers of bars". Research Works, V.D.I., Vol. 212 (1919).

It would follow that „field harmonic motors" with small numbers of phases m_ν have, when the saturation is great at starting, larger parasitic torques than given by theoretical calculations for a permeability of iron equal to infinity. If we check, by calculation, available data regarding measurements [17], [18], [19] of starting torques, we actually find that the depressions of the torque curve corresponding to the high field harmonics $\nu = \left(\frac{N_1}{p} \pm 1\right)$ (and small numbers of phases of cage m_ν) are really larger than given by the theory.

We further see from measurements made [17], [18], [19] that in the case of a large excess in the number of rotor slots over that of stator slots, the fifth and seventh parasitic torques, contrary to expectation, do not assume a very high value. This, too, may perhaps be brought into agreement with the results of the tests on the model, as according to these tests, the product $\varkappa\,\omega\,L$ and, consequently, the maximum torque, too, decreased with the saturation for somewhat larger numbers on phases of cage. The number of phases of cage is, in most cases, of the order of magnitude $m_\nu = 4$ to 14, and this corresponds approximately to the results of the tests on the model for $m = 4, 12$. Furthermore, the fifth and seventh „field harmonic motor" is heavily pre-saturated by the fundamental field and the higher field harmonics.

The slanting of the slots has a very great influence on the coupling factor owing to the effect of the factor [16]):

$$k^2_{\gamma,\nu} = \frac{\sin^2 \frac{\nu\gamma}{2}}{\left(\frac{\nu\gamma}{2}\right)^2} \tag{57}$$

The factor $k_{\gamma,\nu}$ is plotted in Fig. 11. The full effect of slanting the slots can only be garanteed if the bars are insulated and therefore the current of conductors cannot partly close through the iron laminations.

Effect of the field harmonics due to the slots.

It is a well-known fact that the field harmonics due to the winding

$$\nu = \frac{N}{p} - 1, \left(\frac{N}{p} + 1\right)$$

are reinforced (weakened) by the field harmonics with same number of poles, due to the slots [20]), in approximately the following proportion (see also Section III, equation 14):

$$k_N = \frac{\left|\mathfrak{J}_k \pm \nu\,\mathfrak{J}_0\,(k_c - 1)\right|}{\left|\mathfrak{J}_k\right|} \tag{58}$$

The + (—) sign refers to the $\frac{N}{p} - 1$ and $\left(\frac{N}{p} + 1\right)^{th}$ field harmonic. In the case of the dangerous $\left(\frac{N}{p} + 1\right)^{th}$ field harmonic due to the winding, which revolves in the synchronous direction, the parasitic torque is thus somewhat weakened by the field harmonic due to the slots, contrary to the most prevalent views.

[18]) Wandeberg, Scientific Publications of the Siemens Concern, Vol. I (1922), page 102.
[19]) Möller, „On the starting torques of three-phase squirrel cage motors", Arch. El., Vol. 24 (1930), page 401.
[20]) Fritze, „On the distortion of the field, pressure and current curve of the three-phase induction motor", Arch. El., Vol. 10 (1922), page 377.

Approximation formula for the calculation of the asynchronous parasitic torques.

Hansen [21]) takes the following formula (expressed in our mode of notation) for the leakage coefficient of the field harmonics:

$$\tau_{\nu,B} = \tau' \nu^2 \tag{59}$$

τ' is the leakage coefficient of the squirrel cage winding for the fundamental field. This formula is not correct, as can be seen from the above theoretical considerations, as it gives for the leakage coefficient, for instance, for $\frac{m_2}{\nu} = 1, \frac{1}{2}, \frac{1}{3}, \ldots$ a finite value, while the latter should be infinite (see, for example, the curve in Fig. 14).

The formulae which are correct theoretically apply, however, only to the ideal case, where the permeability is infinity and do not give accurate values in practice, as, under short-circuit conditions, the teeth of the motors are always very heavily saturated. With the approximation formula 59 smaller values are obtained for $\tau_{\nu,B}$ than with the theoretical formulae. For this reason, it leads nearer the reality, specially in the case of the $\left(\frac{N}{p} \pm 1\right)^{th}$ field harmonics, than the theoretical formulae, as the leakage coefficient is weakened by the saturation (as mentioned above).

Furthermore, equation 59 is very simple and it is, therefore, worth while to combine it with the approximate equations 45, 58 and with the accurate equations 48, 53, so as to obtain a resulting approximation formula which, it is true, does not give reliable values from a quantitative point of view, but at least shows in a general way the influence of the individual factors, and lends itself to comparative calculations.

$$D_\nu = \frac{m_1}{2} X_{1,0}\, I_k^2 \left(\frac{k_\nu}{k_1}\right)^2 \frac{k^2_{\gamma,\nu}}{\nu\,(1 + \tau'\nu^2)} \text{ syn. watts} \tag{60}$$

or for the $\left(\frac{N}{p} \pm 1\right)^{th}$ field harmonic:

$$D_\nu = \frac{m_1}{2} X_{1,0}\, I_k^2 \frac{k^2_{\gamma,\nu}\, k^2_N}{\nu\,(1 + \tau'\nu^2)} \tag{61}$$

(for $\frac{k_\nu}{k_1}$, see Table 2; for $k_{\gamma,\nu}$ see Fig. 11; for k_N, see equation 58).

Of course, for $\frac{m}{\nu} = 1, \frac{1}{2}, \ldots$, the above approximation formula no longer holds good; the parasitic torque is, in these cases, zero.

Example: A squirrel cage motor with $m_1 = 3$, $q = 3$ in the stator and with non-slanting slots, would have at about $\frac{n_{syn}}{7}$, $\frac{n_{syn}}{19}$, deep depressions in the torque curve. In order to remedy this, the winding pitch is to be shortened ($y = 8/9$) and the slots are to be given a slant amounting to the pitch of stator slots. It is proposed to calculate roughly to what extent the parasitic torques are thereby reduced. We obtain the values of $\frac{k_\nu}{k_1}$ and $k_{\gamma,\nu}$ for the above motor from the Table 2 and the curves in Fig. 11.

Table 7.	y	γ	$\left(\frac{k_7}{k_1}\right)^2$	$\left(\frac{k_{19}}{k_1}\right)^2$	$k^2_{\gamma,7}$	$k^2_{\gamma,19}$
Before the alteration	9/9	0°	.034	1	1	1
After the alteration	8/9	20°	.0042	1	.6	.0027

[21]) Hansen, Torque components due to space harmonics in induction motors, J. A. I. E. E., Vol. 41 (1922), page 928.

As, according to equation 60, the parasitic torque is proportional to the product $\left(\frac{k_\nu}{k_1}\right)^2 k^2_{\gamma,\nu}$, the torque is reduced as follows in the case of our example:

for $\frac{n_s}{7}$ approximately in the ratio $\frac{.0042 \times .6}{.034 \times 1} = .074$

for $\frac{n_s}{19}$ approximately in the ratio $\frac{1 \times .0027}{1 \times 1} = .0027$

Even the method of calculation of the parasitic torques set out by Andronescu [14]) does not lead to accurate results, as the influence of the saturation is also neglected there. Furthermore, Andronescu like Hansen [21]) does not calculate the differential leakage of the squirrel cage winding (for which no formulae were known at the time), but the „leakage between top of teeth".

Recapitulation of Section IV, 2 A.

In the case of standard three-phase squirrel cage motors, the following field harmonics are dangerous: the seventh and the $\left(\frac{N_1}{p} + 1\right)^{th}$ field harmonic, as both are relatively strong and cause parasitic torques in the synchronous direction.

The effect of the seventh field harmonic can be remedied by shortening the pitch of the stator winding by about $^1/_7$ of the pole pitch, as the factor $\left(\frac{k_\nu}{k_1}\right)^2$ (Table 2) then drops to zero or to a very small value. The effect of the $\left(\frac{N_1}{p} + 1\right)^{th}$ field harmonic is compensated by giving the slot a slant amounting to about the pitch of the stator slots, as the factor k^2_γ (Fig. 11) is thereby reduced to nearly zero.

Numbers of bars of squirrel cage windings much in excess of the number of slots of stator (approx. $N_2 > 1.4\, N_1$) are, as already explained, to be avoided whenever possible.

B) Synchronous parasitic torques [22]).

As explained at the beginning of Section IV, 2, we have, according to equations 40—44, a synchronous torque (of the type represented by the curve in Fig. 1 b) when a winding or slot field harmonic of the stator has the same number of poles as that of the rotor and both revolve at the same speed, that is to say, have the same cyclic frequency (in relation to the stator). The stator field harmonic (designated by the index ν) has the same cyclic frequency as the system, the rotor field harmonic (designated by the index μ) has the cyclic frequency such as given by equation 18 (Section III). We have therefore:

$$\omega_\nu = \omega_\mu = \pm\, \omega = \omega\left[\pm\, s + (1-s)\,\mu\right] \qquad (62)$$

The + (—) sign in front of ω refers to a stator field harmonic revolving synchronously (anti-synchronously), and, in a like manner, a + (—) sign in front of s corresponds to a rotor field harmonic revolving synchronously (anti-synchronously). The solutions of equations 62 are as follows, according to the relative direction of rotation of the two field harmonics:

$v = (1 - s) = 0$
when the stator field harmonic revolves synchronously (anti-synchronously) and the rotor field harmonic revolves synchronously (anti-synchronously) (63)

$v = (1 - s) = \frac{2}{\mu + 1}$
when the stator field harmonic revolves synchronously and the rotor field anti-synchronously (64)

$v = (1 - s) = -\frac{2}{\mu - 1}$
when the stator field harmonic revolves anti-synchronously and the rotor field synchronously (65)

($v = 1 - s = \frac{n}{n_{syn}}$ is the relative speed of the rotor).

The maximum value of the synchronous torque would have to be calculated by means of the equation 44. The most dangerous of the three cases (equations 63—65) is that of equation 64, which is encountered for the synchronous direction of rotation. The torques occurring at standstill (equation 63) are specially objectionable in the case of single-phase induction motors with starting devices which only give a small starting torque at standstill. When field harmonics with the same number of poles in the stator and rotor occur in the case of single-phase induction motors, there are always synchronous torques according to the equations 63—65, that is to say, at standstill, and for synchronous, anti-synchronous operation, due to the fact that single-phase motors when starting have a heavy inverse rotating field.

The possible parasitic speeds, according to equations 64, 65, for three-phase motors, are as follows:

Table 8.

Stator field harmonic: $\nu =$	(−) 5	(+) 7	(−) 11	(+) 13	(−) 17	(+) 19	(−) 23	(+) 25	(−) 29	(+) 31
Relative depression speed: $v =$	$-^1/_2$	$+^1/_4$	$-^1/_5$	$+^1/_7$	$-^1/_8$	$+^1/_{10}$	$-^1/_{11}$	$+^1/_{13}$	$-^1/_{14}$	$+^1/_{16}$

The strongest synchronous torques are again produced by the $\left(\frac{N}{p} \pm 1\right)^{th}$ winding and slot field harmonics. We thus have the following relation:

$$\nu = \mu = \frac{N_1}{p} \pm 1 = \frac{N_2}{p} \pm 1 \qquad (66)$$

$$\text{hence:} \quad N_2 - N_1 = 0,\ +\ 2\,p\,,\ -\ 2\,p \qquad (67\,a, b, c)$$

The depressions occur for relative speeds, such as expressed by equations 63–65, with values: $v = 0,\ +\frac{1}{\frac{N_2}{2\,p}},\ -\frac{1}{\frac{N_2}{2\,p}}$ (68 a, b, c)

There are also noticeable depressions, when winding and slot field harmonics, other than the $\left(\frac{N}{p} \pm 1\right)^{th}$ meet, as has been found from the exhaustive measurements made by Moeller [22]). As the value of the torque is given by the product of the amplitude of the waves of the stator and rotor har-

[22]) The correct theoretical explanation of synchronous parasitic torques was given by the author in 1929 (Krondl, „The parasitic torques in induction machines", Elektrotechnicky Obzor, April 1929, page 308; also somewhat later and still more in detail in an internal report of the Oerlikon Company, July 1929). Later on, there appeared the following papers: Moeller „On the torques when starting three-phase squirrel cage motors", Arch. El., Vol. 24 (1930), page 401; Dreese, „Synchronous motor effects in induction machines", J. A. I. E. E., Vol. 49 (1930), page 938. The priority belongs, however, to Dreyfus (34th proceedings - in Swedish - of the Swedish Academy of Engineering, Stockholm, 1924). The work of Dreyfus, like the above papers of the author, have not become generally known.

monics (equation 44), there is a noticeable torque, when at least one of the amplitudes is great.

Parasitic torques occur at standstill, not only when the number of slots of stator and rotor are the same (equations 67a, 68a), but also, to a lesser extent, in the case of every slipring motor with the same number of phases on the primary and the secondary side, as the series of field harmonics which are produced by the two are composed of the same sequence figures (for instance, in the case of three-phase motors $\nu = \mu = 5, 7, 11, 13, 17, 19, \ldots$) and the stator and rotor field harmonics run synchronously in relation to each other at standstill.

In the case of numbers of slots such as given by the equation set out in Section IV, 1:

$$c_1 \frac{N_1}{p} \pm 1 = c_2 \frac{N_2}{p} \pm 1 \qquad (36)$$

the high field harmonics:

$$\nu = c_1 \frac{N_1}{p} \pm 1, \; \mu = c_2 \frac{N_2}{p} \pm 1 \qquad (69)$$

also meet (the smaller c_1, c_2, the greater their amplitude). Numbers of slots corresponding to equation 36 are therefore to be avoided, when approx. $c_1, c_2, \leqq 2$ (also on account of production of noise, see Section IV, 1).

The fact that a very heavy parasitic torque occurs for 24/28 slots, 4 poles, has been known for a long time. As the depression in the torque occurs here at $^1/_7$ of the synchronous speed, there was a belief that it was due to the seventh field harmonic, and its exceptional strength was explained by the fact that the rotor forms a single-phase winding for the seventh harmonic. This assumption is, however, not correct as has been shown in Section IV, 2 A, and the parasitic torque is not due at all to the seventh but to the thirteenth field harmonic.

In Table 8, are given some parasitic speeds which do not correspond at all to the synchronous speed of a field harmonic; for instance, $^1/_2$, $^1/_4$, $^1/_8$, $^1/_{10}$, $^1/_{14}$, $^1/_{16}$, etc.

The accuracy of the theory evolved is confirmed by numerous measurements: Stiel [17]), Wandeberg [18]), Moeller [22]), Dreese [22]); in the following table, we just give a few examples such as encountered in practice:

Table 9.

2 p	N_1	N_2	v	Remarks
4	24	28	$^1/_7$	Squirrel cage motor
4	36	40	$^1/_{10}$	„
6	36	42	$^1/_7$	„
2	30	32	$^1/_{16}$	„
4	36	32	$-^1/_8$	Slipring motor
2	18	16	0	Single-phase squirrel cage motor

Example: Stiel [17]) has measured, on a three-phase four-pole motor with 24/28 slots, a very deep depression in the torque curve at $\frac{n_{syn}}{7} = 214$ RPM. We know that the latter is caused by a synchronous parasitic torque of the thirteenth field harmonic. The particulars of the motor were: output 1 HP, bore 12 cm, width of core 6 cm, number of turns 256, connections delta, no-load current 2.1 amps, short-circuit current 26 amps. On the basis of these data, we can calculate the following quantities for short-circuit conditions at nominal pressure: stator $B_{13} = 5800$ gauss, rotor $A'_{13} = 670$. If these values are introduced in equation 44, we have:

$$D_{13} = 4200 \text{ syn. watts.}$$

At 91% nominal pressure, a synchronous parasitic torque of about 2100 syn. watts was measured, which is equivalent at nominal pressure to $D_{13} = 2500$ syn. watts. The value calculated theoretically is larger, as the saturation is neglected. The parasitic torque measured is about three times the nominal torque and the motor is utterly useless, as even at light load it does not reach full speed.

Slanting of the slots.

When the slots are slanted to the extent of the electric angle γ, the maximum torque (equation 44) is reduced in the proportion given by the following expression (see Section IV, 1 and IV, 2 A):

$$k_{\gamma,\nu} = \frac{\sin \frac{\nu\gamma}{2}}{\frac{\nu\gamma}{2}} \qquad (38)$$

where ν is the order of the field harmonic, which causes the parasitic torque ($k_{\gamma,\nu}$ is plotted in Fig. 11). The synchronous parasitic torque varies with $k_{\gamma,\nu}$, whilst the asynchronous parasitic torque alters with $k^2_{\gamma,\nu}$. In view of this, it is necessary, in order to reduce the synchronous depressions, to adhere to the most favourable slanting with greater care than for obtaining a reduction of the asynchronous depressions.

As already mentioned in Section IV, 2 A, the full effect of the slanting can only be guaranteed when insulated bars are used, as otherwise the current of the bars may close partially through the iron laminations. According to measurements by Dreese [22]), the minimum of the synchronous parasitic torque caused by the ν^{th} field harmonic does not occur for an inclination of $^1/_\nu$ of the double pole pitch, as we would have to assume to be the case theoretically (equation 38), but for an inclination about 50% larger. The author in question gives, it is true, no data regarding the insulation of the rotor bars. It is, however, probable that the bars were not insulated and that this affords an explanation for the discrepancy between the results of measurement and those of the formula 38.

The numbers of slots classified in this section as dangerous, that is to say, mainly those governed by the relation $N_2 - N_1 = 0, \pm 2p$ (equation 67), are also to be avoided specially in the case of non-slanted slots, for the reason that they give rise to resonance harmonics in the system. The strong $\left(\frac{N_2}{p} \pm 1\right)^{th}$ field harmonic of the rotor has for these conditions, in the stator, the same winding factor as the fundamental field, that is to say, nearly 1 and it induces in the stator winding a high frequency voltage of the order of magnitude of, for example, about 10 to 20% of the rated pressure. In most cases, this voltage harmonic does not make itself felt at all, at the terminals, as it is absorbed before then in the reactance drop of the stator winding connected to the system; if, however, there is a capacity in the system which is in resonance with the reactances, excess voltages will occur which may lead to the destruction of the insulation.

Conclusion.

The complicated question of the parasitic forces, and of the phenomena to which they give rise, is not covered in all its details by the theory. Moeller[22]) has, for instance, ascertained the existence of a few torque depressions of a synchronous nature, for which there is still, for the present, no explanation. When dealing with the theoretical study of oscillations and sound, the assumption has been made, for simplification purposes, that the „constants" of the oscillation equation (see Section II, equations 2, 3, 4) are actually constant and that there are therefore no „combination tones". This assumption does undoubtedly not always agree with the actual conditions in the case of the complicated mechanical oscillating systems of electric machines.

We do not want to pretend that apart from the phenomena due to parasitic forces, explained in this paper, there may not occur also other ones which cannot for the present be explained by the theory. The data collected up to now tend to show, however, that the more important instances of such disturbances are covered by the theory.

Tests remain, however, an important means for supplementing the theory. When recording the actual results obtained with different sizes of machines and numbers of slots, the strength of the sound and the degree of audibility, as well as the probable cause of the good or bad results, should be noted. The methods of measurement described in Section II facilitate critical investigation. It is necessary to guard against too rapid generalisations, for instance, on the basis of observations made on a single size of machine. The production of sound in electric machines depends, as explained in Section II, to a great extent upon the ability of the constructional parts to oscillate at the frequency of the forces that come into play. This ability to oscillate is governed by the nature of the design adopted and principally by the size of the machine; consequently, it is not possible to generalize on the basis of the results obtained for one size of machine. It may happen that a certain number of slots which is „theoretically bad" gives good results in the case of small machines, but is very bad for large sizes of machines.

I wish here to thank Professor Dr. Franz Tank of the Federal Technical College, Zurich, for valuable advice given on the subject of acoustics and for the loan of various instruments from his institution.

Some Notable OERLIKON Turbo-Generators.

(see also illustration on front page.)

A certain number of turbo-generators for relatively high working pressures have, of late, been going through the shops at the Oerlikon Works. After building, last year, a turbo-generator for only 1600 KVA at 11000 volts, for a power station in the Dutch East Indies, the Oerlikon Company have recently supplied a generator for 3750 KVA at 13200 volts, 3600 RPM, for Lethbridge in Canada and another one for 25000 KVA at 16000 volts, 3000 RPM, for the Cie. des Mines d'Anzin in France. A duplicate of the latter is now in the course of construction for the same Company. In the case of all these machines, use has been made of a new type of insulation for the slot conductors, in view of the high working pressures and test pressures; this insulation is greatly superior, in regard to dielectric losses, to the shellac-micanite insulation used up to then. The necessity for this new type of insulation arose two years before, in the case of an order for a turbo-generator for 24000 KVA at 10000—11000 volts, 3000 RPM for Hengelo, Holland, for which specially severe conditions were laid down with regard to the insulation. An identical set, which has to satisfy the same conditions, is at the present time in the course of construction for Groningen, Holland. It was laid down, in the case of these machines, that the angle of losses was not to exceed a given low value during the insulation tests of the individual coils, and that the so-called „ionisation bend", i. e. the value of test pressure, after which the dielectric losses begin to increase more rapidly than the square of the test pressure, was to be higher than the pressure encountered during service in the windings. It was further stipulated that all coils were to be subjected to a test pressure 4½ times the working pressure for 2 minutes and that certain test coils of exactly the same design were to withstand 5½ times the latter for 10 hours without discharge or flash-over, when under the same conditions as when inserted in the generator. The generators had thus to be equivalent, as regards insulation, to machines for a working pressure of 15000—16000 volts. These conditions were all satisfied by the generators for Hengelo and Groningen.

The good results obtained by the Oerlikon Company with this new type of insulation led to its adoption also in cases where such conditions as laid down for the generators for Holland were not stipulated, but where the high working pressures justified the use of this better insulation, and in particular for all generators for working pressures of 15000 volts and more.

In the illustration on the front page, the second machine from the left is the above-mentioned generator for Lethbridge, wound for 13200 volts, and on the extreme right, the generator for Groningen for 11000 volts and that for the Mines d'Anzin for 16000 volts, the winding not yet being inserted in the case of the latter two. In front, on the left, we have a generator for 25000 KVA at 11000 volts, 3000 RPM, for Algiers and in the middle of the illustration a generator for 40000 KVA at 5700 volts, 3000 RPM. The casing of the latter is of welded construction. The covering of the casing is made in several sections which can be dismantled independently. In view of this, the core is easily accessible from the outside for the purpose of cleaning, and furthermore this design with its subdivisions affords a pleasing appearance.